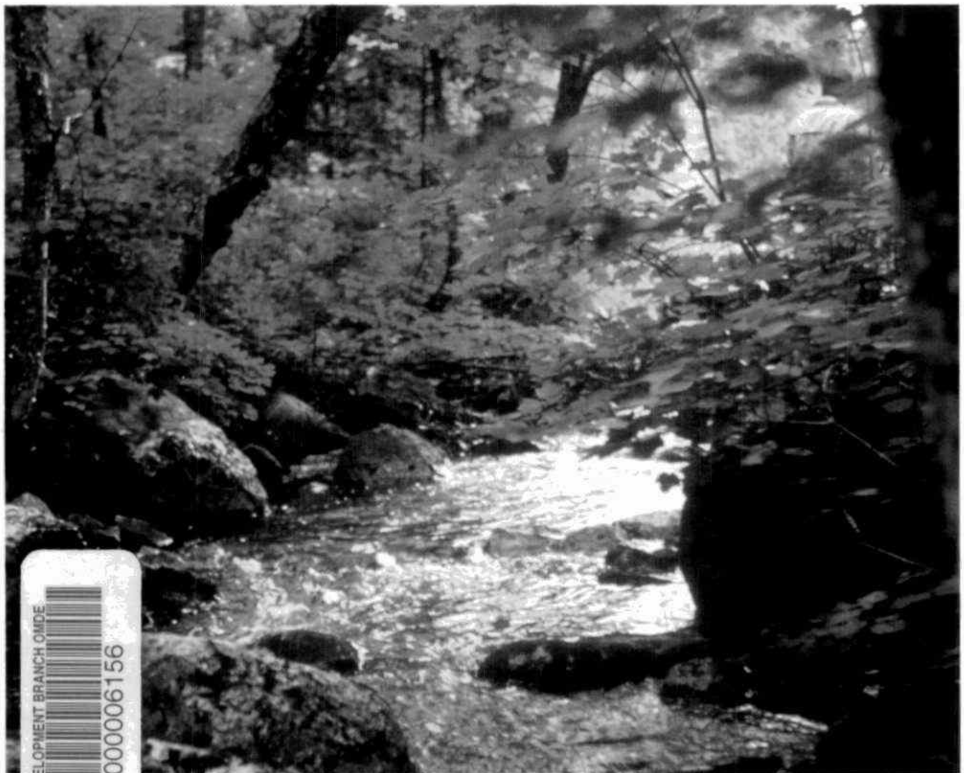
Federal/Provincial Research and Monitoring Coordinating Committee (RMCC)



THE 1990 CANADIAN LONG-RANGE TRANSPORT OF AIR POLLUTANTS AND ACID DEPOSITION ASSESSMENT REPORT

Part 1

EXECUTIVE SUMMARY

1990

ACID RAIN

PLUIES ACIDES

BC Environment

Gouvernement du Québec
Ministère de l'Environnement

Alberta
ENVIRONMENT

New Brunswick Nouveau Brunswick

Saskatchewan Environment and Public Safety

Prince Edward Island Department of the Environment

Nova Scotia
Department of the Environment

Manitoba Environment

Environment Ontario

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RESEARCH AND MONITORING

COORDINATING COMMITTEE (RMCC)

THE 1990 CANADIAN LONG-RANGE TRANSPORT OF AIR POLLUTANTS AND ACID DEPOSITION ASSESSMENT REPORT

PART 1

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1990

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SUMMARY

The Eastern Canadian Sulphur Dioxide (SO_2) Control Program is well underway. The seven eastern provinces - Manitoba, Ontario, Quebec, New Brunswick, Nova Scotia, Prince Edward Island and Newfoundland - are currently implementing programs and regulations that will reduce SO_2 emissions from the base level of 4,516 kilotonnes in 1980 to 2,300 kilotonnes in 1994. The emission control programs focus on ten major sulphur dioxide emitters in eastern Canada, all within the mining and energy sectors. The companies which operate these ten emission sources will invest a total of $1.7 billion in capital projects between 1987 and the end of 1993 to meet the emission reduction requirements.

An intensive research effort on the Long Range Transport of Air Pollutants (LRTAP), including acid rain, has been underway for over a decade. Significant advances have been made in determining the emissions of sulphur dioxide and nitrogen oxides, their concentrations in ambient air, the associated deposition of acids, and the damages to the environment as a result of emissions of these pollutants.

Significant decreases in SO_2 concentrations in air and sulphate concentrations in precipitation (up to 30%) have been observed at a number of sites in eastern Canada over the last decade. These locations are in, or downwind of, regions in which SO_2 emissions have decreased by more than 10 percent. During the 1980s there has been little change in nitrate levels in precipitation, consistent with the constant nitrogen dioxide emissions.

In the area east of the Manitoba-Ontario border and south of James Bay, there are approximately 800,000 water bodies greater than 0.18 hectares in size, half of which are sensitive to the effects of acid deposition. It is estimated that there are more than 31,000 acidic lakes greater than 0.18 hectares and 14,000 acidic lakes greater than 1 hectare in size.

There is conclusive evidence that acidification causes adverse effects to many aquatic organisms. It is now understood that the total number of fish species and other classes of aquatic biota start to decrease when the pH of a lake falls below 6.0, well before a lake is considered to be completely acidified.

The sulphur dioxide emission reductions that have been achieved to date in Canada and the U.S. have resulted in some encouraging recovery trends in surface waters.

The current episode of maple decline in Canada is more severe and extensive than declines that have occurred in the past. Although specific cause-effect relationships have not been demonstrated, acidic deposition and ozone are thought to be factors contributing to maple decline in Quebec and Ontario.

Acidic fog has been implicated as one of the agents causing white birch deterioration along the Bay of Fundy coast in New Brunswick.

High concentrations of ground level ozone have caused significant losses to agricultural crops in eastern Canada and British Columbia.

Ground level ozone and acid aerosols are the components of LRTAP which are most likely to be affecting human health in a direct way. A Canadian study has found small decreases in children's lung function during periods of high air pollution at a rural site in southern Ontario without local sources of air pollution. Two other Canadian studies have compared the respiratory health of children in a region which experiences high levels of LRTAP with a region with low levels. The children in the more polluted area exhibited decreases in lung function and had a higher incidence of respiratory infections.

Scientists have found an association between high daily air pollution levels in summer and hospital admissions for respiratory conditions. Sulphuric acid aerosol is the pollutant most likely responsible for this association.

The target load of 20 kilograms per hectare per year (kg/ha/yr) of sulphate in precipitation is the objective of Canadian efforts to reduce acid rain. The value was derived from limited data available in the early 1980s and was based mainly on the loss of sport fish which occurs at approximately pH 5.3. It was recognized at that time that very sensitive areas would not be protected by this target and that further evaluation would be needed when more information was available. It was also recognized that a SO_2 control plan that would bring the maximum deposition in any sensitive area down to 20 kg/ha/yr would also mean that most other sensitive areas would receive substantially less wet sulphate deposition.

New information gathered in the past few years has been analyzed to determine the "critical load" for aquatic ecosystems. The critical load is the highest deposition of acidifying compounds that will not cause chemical changes leading to long-term harmful effects on the overall structure or function of the aquatic ecosystem. Critical load information can be used along with information on economic and social concerns in the selection of target loads and the design of control programs.

New aquatic effects data and the new criteria of pH greater than or equal to 6.0 needed to protect aquatic ecosystems have been used in aquatic models to predict critical load values for different regions of eastern Canada. These values range from less than 8.0 in Atlantic Canada to more than 20 kg/ha/yr of sulphate in precipitation in some of the less sensitive regions of Ontario and Quebec.

Analyses of the effectiveness of the Canadian and U.S. SO_2 control programs have been undertaken through the use of atmospheric and aquatic models. Major improvements in lake chemistry and biota are predicted for Ontario and Quebec. The models do not predict much improvement in aquatic conditions in the very sensitive areas of New Brunswick, Nova Scotia and southern Newfoundland even though wet sulphate deposition is predicted to be less than 14 kg/ha/yr once both control programs are fully implemented.

TABLE OF CONTENTS

LIST OF FIGURES AND TABLES

FIGURES

TABLES

1.0 INTRODUCTION

An intensive research effort on the Long Range Transport of Air Pollutants (LRTAP), including acid rain and the effects on the Canadian environment, has been underway for more than a decade. At the same time there has been considerable progress in reducing emissions of acid forming pollutants: the acid rain control program for eastern Canada has been developed; the western provinces have undertaken research to address questions related to the unique situation in western Canada; protocols have been signed under the auspices of the United Nations Economic Commission for Europe's (ECE) LRTAP Convention committing Canada to reduce national 1980 SO_2 emissions by a minimum of 30 percent by 1993 and limiting NO_x emissions to 1987 levels before 1995; and recently, amendments to the Clean Air Act have been passed in the United States to control acid rain. The year 1990 marks the end of a five year period of special federal funding under the LRTAP IV Cabinet Submission and the end of the U.S. National Acid Precipitation Assessment Program (NAPAP) with the production of its own assessment reports. As we enter into a new decade of research and monitoring it is important that we take stock of what we know about the long range transport of air pollutants and acid rain and the directions for future research and controls.

The 1990 Canadian Long Range Transport of Air Pollutants and Acid Deposition Assessment report is made up of eight parts:

Part 1: Executive Summary
Part 2: Emissions and Controls
Part 3: Atmospheric Sciences
Part 4: Aquatic Effects
Part 5: Terrestrial Effects
Part 6: Human Health Effects
Part 7: Socio-economic Studies
Part 8: Quality Assurance Studies

Each report has been based on a series of questions. The Executive Summary poses the following seven additional questions which attempt to integrate the results arising from the different areas of study:

1. What steps have been taken to control LRTAP emissions in Canada?

2. How have Canadian industries and utilities responded to Eastern Canada's Sulphur Dioxide Control Program? What costs are being incurred and how will these costs affect industries and local communities?

3. What are the past and current emission levels of sulphur dioxide, nitrogen oxides, and volatile organic compounds (VOCs)?

4. What has been the response of the Canadian environment to the long range transport of airborne pollutants?

5. What changes can be expected as a result of full implementation of the sulphur dioxide control programs in the United States and Canada? Will these control programs be sufficient to protect the Canadian environment?

6. What are the potential short-term mitigative measures, their likely consequences and anticipated success?

7. What are the future directions for LRTAP research and control activities?

Many of the answers to these questions have direct implications on the environmental policies of the federal and provincial governments. Therefore, the reports will be forwarded to the Federal/Provincial LRTAP Steering Committee and the Canadian Council of Ministers of the Environment which have the responsibility for policy setting.

We sincerely thank all of the people involved in the production of the assessment report for their dedication and time consuming efforts in assembling and analyzing the large volume of scientific information. Contributors and reviewers are listed in Appendix 1. Special thanks also go to Tom Chivers, Adam Fenech, Guy Fenech, Kelly Gauss, James Hart, Nicole Louissaint, Carrie McKay, Aaron Mattson, Susan Moore, Shelagh Roe, Liz Sahsuvaroglu, Anne Tortolo, Ruth Tung, and Albert Wright of the Atmospheric Environment Service for their assistance in preparing the reports. The photograph of building damage shown on the back cover of each report is courtesy of Martin Weaver.

Copies of all reports may be obtained from:

Environmental Integration Services Branch
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Phone: (416) 739-4645/4240

Tom Brydges, Bill Hart and Sue Milburn

1.1 WHAT STEPS HAVE BEEN TAKEN TO CONTROL LRTAP EMISSIONS IN CANADA?

Concern over the long-range transport of air pollutants (LRTAP) in Canada has focused on the damage caused by acid rain and ground-level ozone. In response, the federal and provincial governments have developed a cooperative approach to domestic emission control which meets national goals while respecting provincial autonomy and the need for regional flexibility. Since LRTAP is a transboundary problem, Canada has promoted and participated in both bilateral and international agreements to complement its actions at home.

1.1.1 ACID RAIN

The damages due to acid deposition are most severe in eastern Canada. They are mainly caused by sulphur dioxide (SO_2) emitted from smelters and power plants in eastern Canada, and from power plants in the midwestern and northern United States [see Figure 1.1.1]. Emissions of nitrogen oxides (NO_x) contribute to the acidity of precipitation; however, they are not currently a major cause of surface water acidification in eastern Canada.

In the early 1980s, based on the limited information available at the time, Canada developed a target loading of 20 kilograms per hectare per year of wet sulphate deposition as a maximum deposition level. This target was seen to be protective of moderately sensitive aquatic ecosystems and became the objective of the SO_2 control efforts.

The Eastern Canadian SO_2 Control Program was established in 1985 whereby the seven eastern provinces agreed to achieve, by 1994, a 50 percent reduction in annual SO_2 emissions from the 1980 allowable base case value of 4,516 kilotonnes. Over 2,000 kilotonnes of SO_2 emission reductions have been allocated among the provinces, and upper limits on annual provincial SO_2 emissions were established for 1994 [see Figure 1.1.2]. By 1991, the Canadian Council of Ministers of the Environment will allocate the remaining 174 kilotonnes of SO_2 reductions among the provinces.

In order to facilitate the control program, the federal government has been supporting the development and demonstration of technologies which reduce SO_2 emissions at their source. Both federal and provincial governments have made funds available to industry to implement controls.

The Governments of Manitoba, Ontario and Quebec have passed regulations to establish legal upper limits on emissions for the large emitters of SO_2. In the Atlantic provinces, where the major sources are provincially owned electric utilities, emission control strategies have been developed to achieve the required reductions.

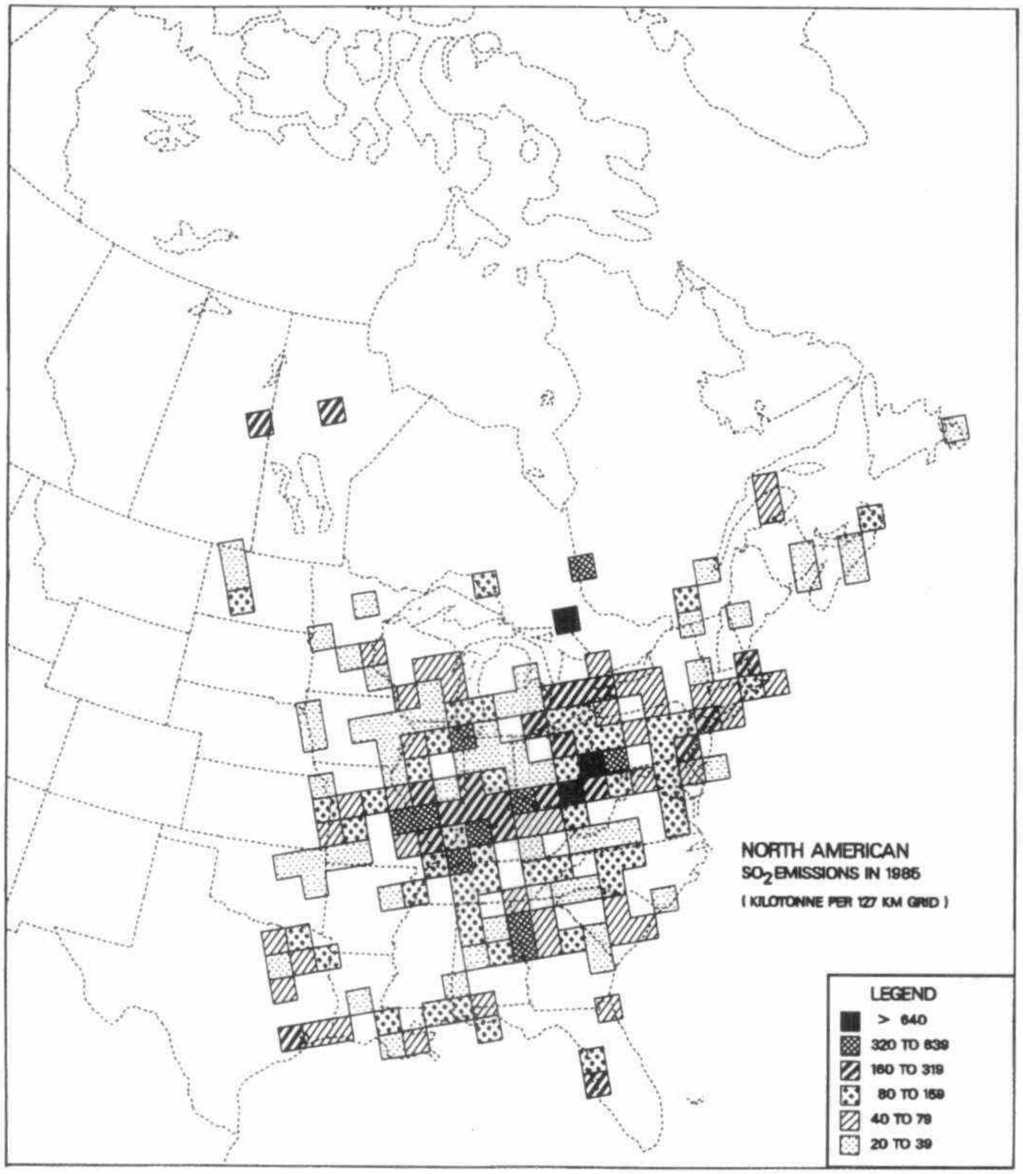
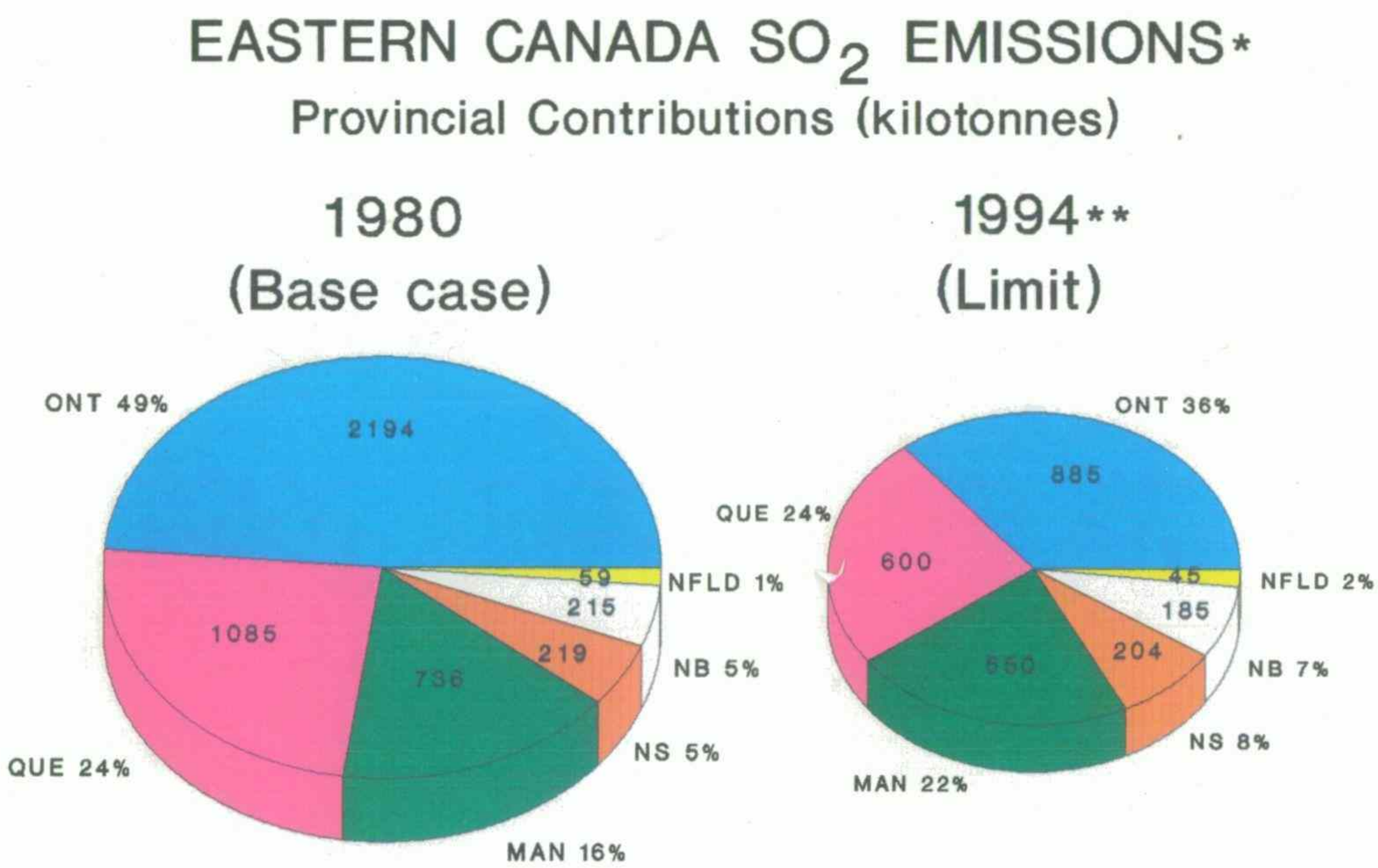


Figure 1.1.1 North American SO_2 Emissions in 1985



* P.E.I. values too small for charts

** An additional 174 kilotonnes of SO_2 reductions will be allocated among the provinces before 1994.

FIG. 1.1.2 Eastern Canada SO_2 Emissions - Provincial Contributions (kilotonnes)

In Quebec, the full SO_2 control programs came into effect in 1990. In all other provinces, full reductions and restrictions on emissions will be in place by 1994. Some interim reduction limits are in place for the major emitters in Ontario as well as for Inco in Thompson, Manitoba.

The federal-provincial agreements, except the Canada-Ontario Agreement, expire at the end of 1994. The Government of Ontario's commitment to cap SO_2 emissions at 885 kilotonnes extends into the future without time limit or expiry date. The agreements covering the six remaining provinces provide for the negotiation of new agreements to extend the reductions or limits beyond 1994.

Atmospheric research has shown that Canadian emission cutbacks alone will not be sufficient to meet the wet sulphate deposition target of 20 kg/ha/yr and must be accompanied by a 50 percent reduction in the transboundary flow of SO_2 from the United States. As a consequence, Canada has encouraged the United States to initiate its own acid rain control program and to conclude a related bilateral accord.

In western Canada, acid rain is a less pressing issue due to lower acid deposition values and generally less sensitive terrain. However, the federal government and the Governments of Manitoba, Saskatchewan, Alberta, British Columbia and the Northwest Territories have recognized the potential for harm in some sensitive regions and have sponsored a coordinated research and monitoring program in western Canada since 1980.

1.1.2 GROUND-LEVEL OZONE

Ground-level ozone, which can have serious human health and vegetation effects, is produced in the lower atmosphere from photochemical reactions involving natural and anthropogenic emissions of volatile organic compounds (VOCs) and NO_x. While domestically produced NO_x and VOC emissions are important contributors to the Canadian ground level ozone problem, in some parts of eastern Canada transported ozone, NO_x and VOCs from United States dominate. During the summer months, about one-half of the Canadian population is often exposed to ozone levels which exceed the national acceptable 1 hour objective of 82 parts per billion.

Canada acted to reduce both NO_x and VOCs emissions from light and heavy duty vehicles starting with the 1988 and 1989 model years. Further reductions to match California standards for automobiles have been announced. Limits on NO_x emissions from power plants have been imposed by the federal and provincial governments.

The Canadian Council of Ministers for the Environment (CCME) have directed that a national Management Plan for solving the NO_x/VOC/ozone problem be developed by the fall of 1990. A draft of this plan was released for public comment in March of 1990 and

was to be considered by Ministers in November of 1990. The plan addresses the reduction of NO_x and VOC emissions from a broad spectrum of sources, including automobiles, power plants, industrial and commercial boilers, stationary engines, and combustion turbines, as well as vapour losses when gasoline is transported, stored and consumed.

1.2 HOW HAVE CANADIAN INDUSTRIES AND UTILITIES RESPONDED TO EASTERN CANADA'S SULPHUR DIOXIDE CONTROL PROGRAM? WHAT COSTS ARE BEING INCURRED AND HOW WILL THESE COSTS AFFECT INDUSTRIES AND LOCAL COMMUNITIES?

The major emitters of SO_2 in eastern Canada are six large copper, zinc and nickel smelters, one iron ore sintering plant and three provincially owned electrical utilities:

- Hudson Bay Mining and Smelting (HBMS), Flin Flon, Manitoba
- Inco, Thompson, Manitoba
- Inco, Sudbury, Ontario
- Falconbridge, Sudbury, Ontario
- Algoma Steel, Wawa, Ontario
- Ontario Hydro
- Noranda, Rouyn, Quebec
- Noranda, Murdochville, Quebec
- New Brunswick Electric Power Commission (NBEPC), and
- Nova Scotia Power Commission (NSPC).

Between 1987 and 1994 the major emitters will invest about $1,700 million in capital projects to reduce their SO_2 emissions. The average annual investment over the period is $248 million per year but, during the final four years, the investment in capital projects will be higher at approximately $352 million per year.

Investments in capital projects will continue beyond the end of 1993. For example, Ontario Hydro will continue to invest about $206 million a year in abatement projects from 1994 to the end of 1998 in order to keep emissions below the limit while allowing for growth in electrical generation. Nova Scotia Power will invest another $170 million between 1994 and 2010 for the same reason.

In some cases, the companies involved in the control program have indicated that they may be able to further reduce emissions after 1994. Hudson Bay Mining and Smelting, Inco (Sudbury), Falconbridge, Ontario Hydro, Noranda (Rouyn), and Nova Scotia Power have indicated that future reductions are possible in the late 1990s or at some time in the next century. However, there are technical and operational factors that must be resolved in the meantime.

1.2.1 SMELTERS

Hudson Bay Mining and Smelting (HBMS) and Inco (Sudbury) are modifying their smelters to reduce emissions and to improve efficiency and competitiveness in world markets. Smelter modernization will: lower operating costs, primarily through reductions in labour and energy requirements; provide for a healthier work environment; and improve metal recovery. The lower operating and maintenance costs will pay off capital investment at Inco (Sudbury) and HBMS over time.

Inco (Thompson) will meet its emission limit by removing more sulphur from the concentrate feed into its furnaces, through the separation and rejection of the pyrrhotite (a mineral high in sulphur) component of the ore.

Falconbridge was modernized in 1978. To meet its 1994 emission limit it will employ a combination of techniques including pyrrhotite rejection, increased roasting and improved operation of electrical furnaces.

Algoma Steel has been meeting its emission limit by reduced production at Wawa, since the mid-1980s, due to market and plant conditions.

An acid plant, where sulphur dioxide gas is captured and made into marketable sulphuric acid, has been constructed at the Noranda-Rouyn smelter in order to reduce emissions by 50 percent. The acid plant came into operation in November, 1989.

Noranda (Murdochville) is a small custom smelter. To meet its 1990 emission limit the smelter will use an acid plant, built in the early 1980s, to capture and treat waste SO_2 gas.

The process changes will have positive and negative effects on operating and maintenance expenses in 1994 and beyond. For example, Inco (Sudbury) expects to save $64 million annually in operating and maintenance costs; HBMS expects some savings; Falconbridge expects expenses to be minimal; Noranda anticipates that its annual expenses will increase at Rouyn; and Inco (Thompson) expects that its operating expenses will increase by at least $13 million annually.

Local and regional employment is expected to increase during the construction phase at HBMS, Inco (Sudbury), and Noranda. Annual operating and maintenance staffs will decrease at HBMS and Inco (Sudbury), however, reductions will be attained through normal attrition as opposed to lay offs. The attrition level at Inco (Sudbury) will more than offset the lower labour requirements of 1994, so Inco will add some 500 new employees in Sudbury by 1994. Falconbridge and Noranda expect no change or little change in operating and maintenance staff. Inco (Thompson) expects operating and maintenance staff to increase by at least 16 person years.

While the federal and provincial governments have made financial assistance available for implementation of SO_2 reductions, to date, Noranda (Rouyn) is the only smelter that has made use of this offer in the form of repayable loans from the federal and provincial governments. One other company, HBMS, has applied for federal and provincial assistance. The other companies will absorb the costs of emission control measures.

1.2.2 ELECTRICAL UTILITIES

The emission limits for electric utilities have been set on a system basis as opposed to individual generating stations or units. To meet their 1994 limits and beyond, Ontario Hydro, New Brunswick Power and Nova Scotia Power must develop strategies to lower or minimize emissions within their future or planned energy systems and not simply their existing systems. Both New Brunswick Power and Nova Scotia Power plan to bring new coal-fired generation on stream before 1994. Ontario Hydro, on the other hand, does not plan to add new coal-fired generation to its system before 1994, and possibly not before the turn of the century.

To reduce emissions from existing generating stations the utilities will either be reducing the sulphur content of fuel or building scrubbers to capture and treat more of the SO_2.

At new stations or units, New Brunswick Power and Nova Scotia Power will use technologies that enable them to control 90 percent of the SO_2 gas produced. To do this, Nova Scotia Power will use circulating fluidized bed combustion technology at its new Point Aconi plant while New Brunswick Power will use conventional combustion technology together with an add-on scrubber.

Over a longer period of time, through to the year 2000 and into the next century, the utilities could make changes to their generating mixes which contribute to lower emission levels. At Ontario Hydro and New Brunswick Power, nuclear power and energy purchases from out-of-province or from non-utility generators have a potential role to play in future energy supply options. In Nova Scotia, the resource of choice for the utility in the 'foreseeable future' is coal. It is expected that demand management initiatives will contribute to the more efficient use of electricity in all three provinces.

Ontario Hydro will spend \$1.7 billion in capital projects during the 1990s to lower emissions. The utility will invest up to \$2.7 billion to fully implement its control measures through to the end of the century. Nova Scotia Power will invest approximately \$300 million over 20 years to reduce SO_2 emissions by about 50 percent of today's levels. Comparable information for New Brunswick Power is not yet available.

At Ontario Hydro, the SO_2 and NO_x control measures are expected to add \$114 million annually to operating and maintenance expenses by the year 2000. New Brunswick Power has also indicated that expenses will increase by at least \$40 million a year.

Comparable Nova Scotia Power costs are estimated to be about $70 million over the period.

Ontario Hydro will finance its investment in capital projects and added operating and maintenance expenses by increasing its rates for electricity. The utility has estimated that its control program will require sustained increases in electricity rates between 1990 and the turn of the century. Initially, the control measures will result in an average 1.0 percent increase in annual rates between 1990 and the end of 1993, followed by an average 2.8 percent increase in annual rates between 1994 and the turn of the century. The rate increases will reach a maximum of 3.4 percent in 1998. Nova Scotia Power indicated that its electricity rates will increase by the rate of inflation and New Brunswick Power has not indicated what rate changes will be required.

Local and regional employment opportunities are expected to increase during the construction phase at Ontario Hydro. For each pair of scrubbers added to its system, about 1,400 person years in construction will be created on site over a five year period. The construction of up to four pairs of scrubbers at Lambton and Nanticoke could generate up to 5600 person years between 1990 and 2000. Annual operating staff will increase by 100 to 240 person years each at Lambton and Nanticoke.

1.3 WHAT ARE THE PAST AND CURRENT EMISSION LEVELS OF SULPHUR DIOXIDE, NITROGEN OXIDES AND VOLATILE ORGANIC COMPOUNDS?

In the last two decades there has been a major decline in North American emissions of SO_2. Between 1980 and 1985, United States emissions decreased about 15 percent from 24.5 to 20.9 million tonnes and, in Canada, about 20 percent from 4.6 to 3.7 million tonnes [see Figure 1.3.1]. These trends can be largely attributed to a combination of regulatory initiatives and process improvements in the metal smelting industry, flue-gas desulphurization for coal-fired electric generating stations and a general shift to cleaner fuels. The major proportion of these emissions (20.2 million tonnes in 1985) come from eastern North America (defined as the states east of the Mississippi River and the provinces east of Saskatchewan) with the Canadian component contributing about 14 percent of the total. Preliminary data for 1986 and 1987 indicate that the decrease in emissions in eastern North America may have levelled off during that period.

The overall annual NO_x emissions for North America, after more than doubling since the early 1950s, decreased by 8 percent from 22.3 to 20.6 million tonnes per year over the period 1980-1985. For the United States, the decrease was about 9 percent (from 20.4 to 18.7 million tonnes) and appears related to decreases in highway vehicle emissions. Canadian NO_x emissions held steady at about 1.9 million tonnes over the 6-year period despite increases in vehicle use and economic activity [see Figure 1.3.2]. As was the case for SO_2, the eastern part of North America also provided the largest NO_x contribution (65 percent) in 1985, with the eastern United States and eastern Canada producing about

12.3 and 1.1 million tonnes, respectively. Preliminary emissions information for 1986 and 1987 suggest that the total NO_x production for eastern North America may have increased slightly since 1985.

Between 1970 and 1985, total hydrocarbon emissions increased by 15 per cent from 2.0 million tonnes to 2.3 million tonnes [see Figure 1.3.3]. Hydrocarbon emissions include both volatile organic compounds and non-photochemically reactive hydrocarbons because inventories did not distinguish between these two hydrocarbon types until 1985. The main sources of hydrocarbon emissions were, and continue to be, gasoline-powered motor vehicles, gasoline distribution and marketing facilities, refineries, petrochemical plants, the application of surface coatings and the use of solvents.

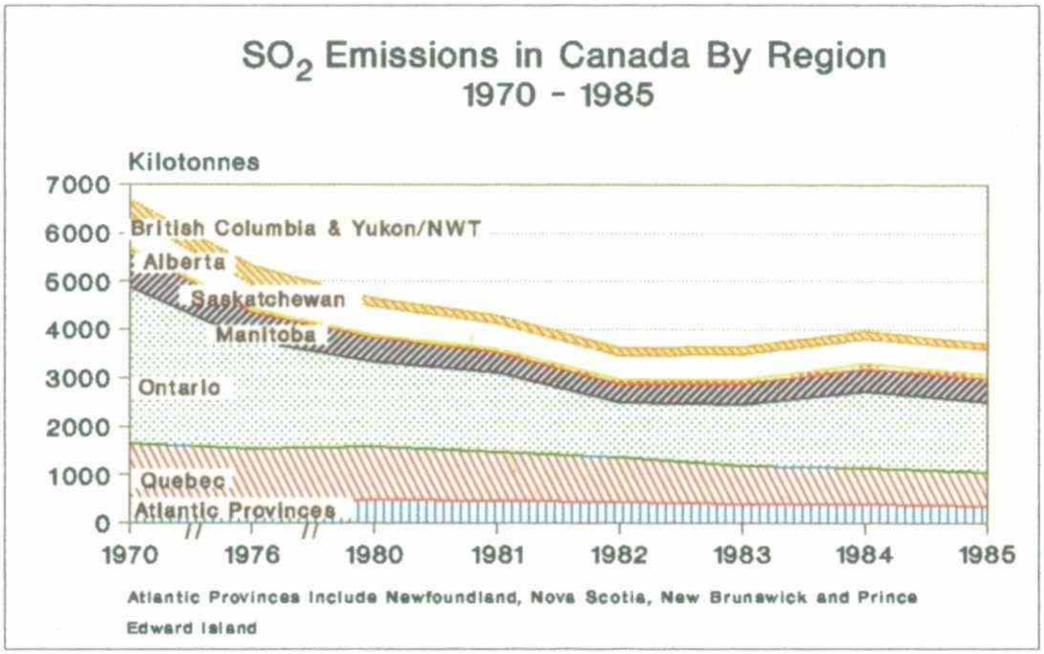


Figure 1.3.1 SO_2 Emissions in Canada by Region (1970 - 1985)

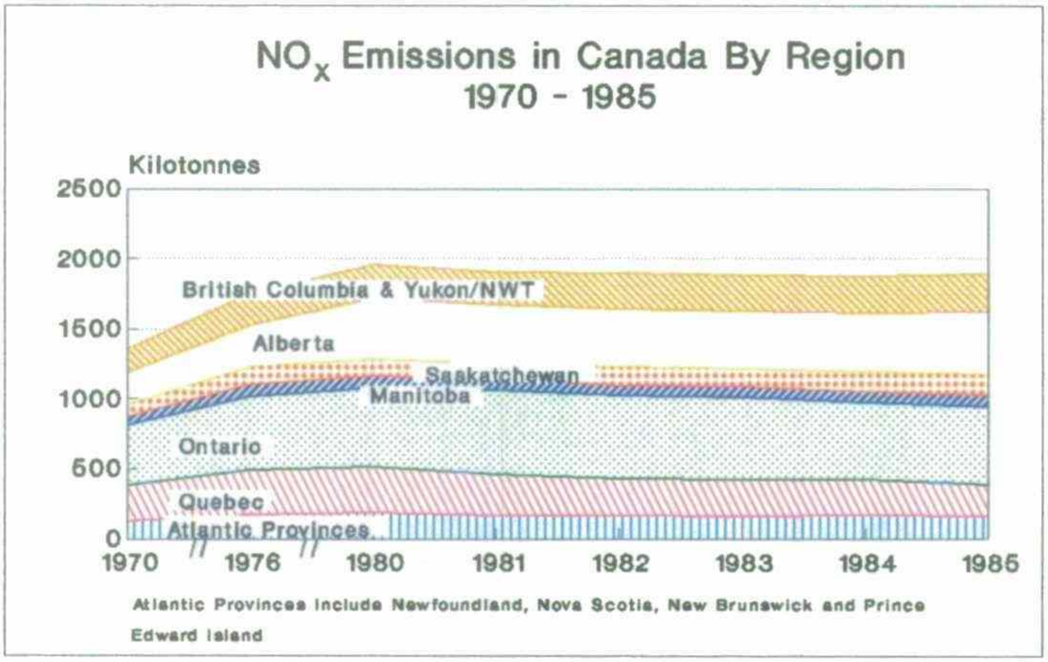


Figure 1.3.2 NO$_x$ Emissions in Canada by Region (1970 - 1985)

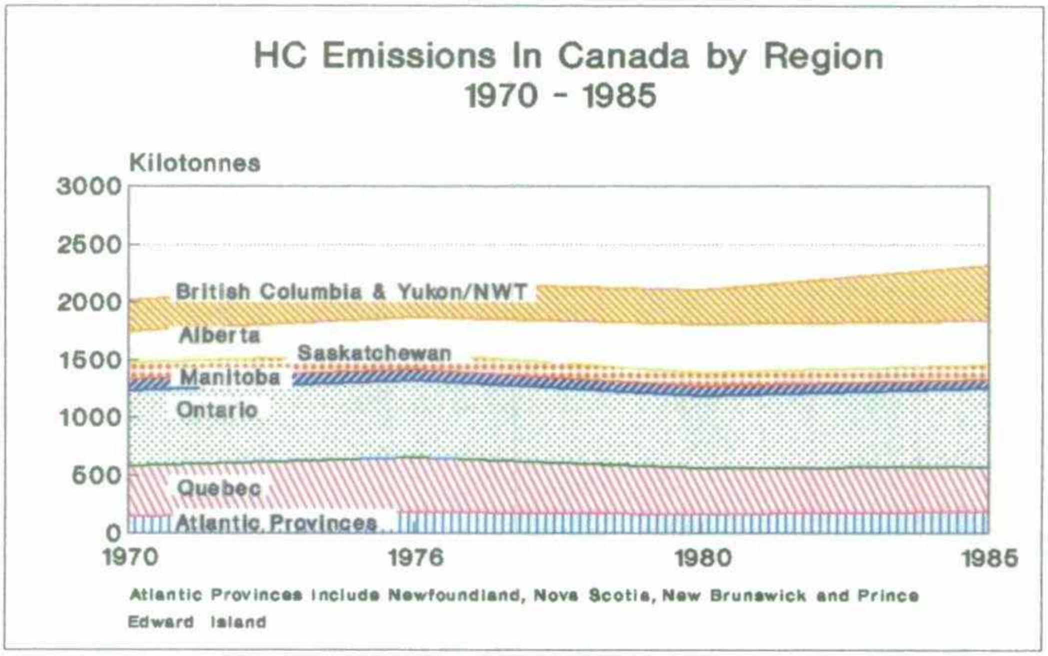


Figure 1.3.3 HC Emissions in Canada by Region (1970 - 1985)

1.4 WHAT HAS BEEN THE RESPONSE OF THE CANADIAN ENVIRONMENT TO THE LONG RANGE TRANSPORT OF AIRBORNE POLLUTANTS?

Since the major acid rain research programs began in the late 1970s, considerable effort has gone into determining the emissions of sulphur (SO_2) and nitrogen (NO_x) oxides, their concentrations in ambient air, the associated deposition of acids to the earth's surface and the resulting damages to aquatic and terrestrial ecosystems, and human health. We now have almost a decade of intensive observations from which important conclusions can be reached concerning the current status of the acid rain problem in Canada.

Quality assurance activities incorporated in the research program have provided the Canadian federal and provincial governments with reliable data to support emission control discussions. Quality assurance programs have been fully implemented in the atmospheric and aquatic research program and are being incorporated in terrestrial studies. Three interlaboratory intercomparison studies have been conducted each year, since 1982, for laboratories contributing data to the LRTAP programs. Most laboratories have shown a significant improvement in performance as a result of participation in these round-robin performance studies.

1.4.1 ATMOSPHERIC CONCENTRATIONS AND DEPOSITION

Air and precipitation monitoring programs have been in place in Canada since the late 1970s, and have yielded substantial, high quality data sets. These measurements continue to confirm that a geographical relationship exists between emissions of SO_2 and NO_x, and the air concentrations and wet deposition of acid substances (sulphate and nitrate) with the maxima in the atmospheric patterns being over, or immediately downwind of, the maxima in the emissions density. Temporal variations of acid deposition in eastern Canada are consistent with the changes in emissions from eastern North America over the period 1980-1987. There has been a shrinkage in the total area receiving wet sulphate deposition loadings greater than 20 kg/ha/yr but no consistent large-scale change in wet nitrate deposition patterns [see Figures 1.4.1 and 1.4.2].

At a number of locations in eastern Canada, where aerometric measurements have been made since the late 1970s or early 1980s, decreases were observed in atmospheric SO_2, the predominant atmospheric sulphur compound in air. These locations are in, or downwind of, regions in which SO_2 emissions have decreased by more than 10 percent. Changes of sulphate and nitrate in precipitation are also generally consistent with upwind SO_2 and NO_x emissions [see Figures 1.4.3 and 1.4.4].

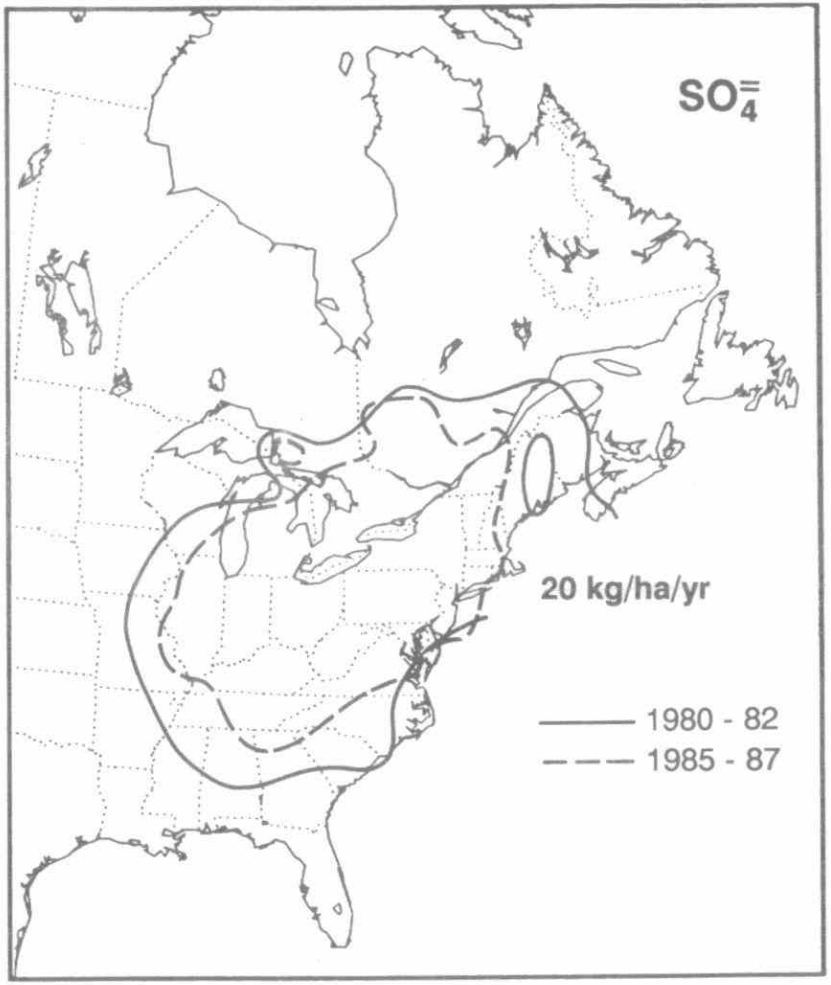


Figure 1.4.1: Superposition of the 20 kg/ha/yr excess sulphate deposition isopleths for the periods 1980-82 and 1985-87.

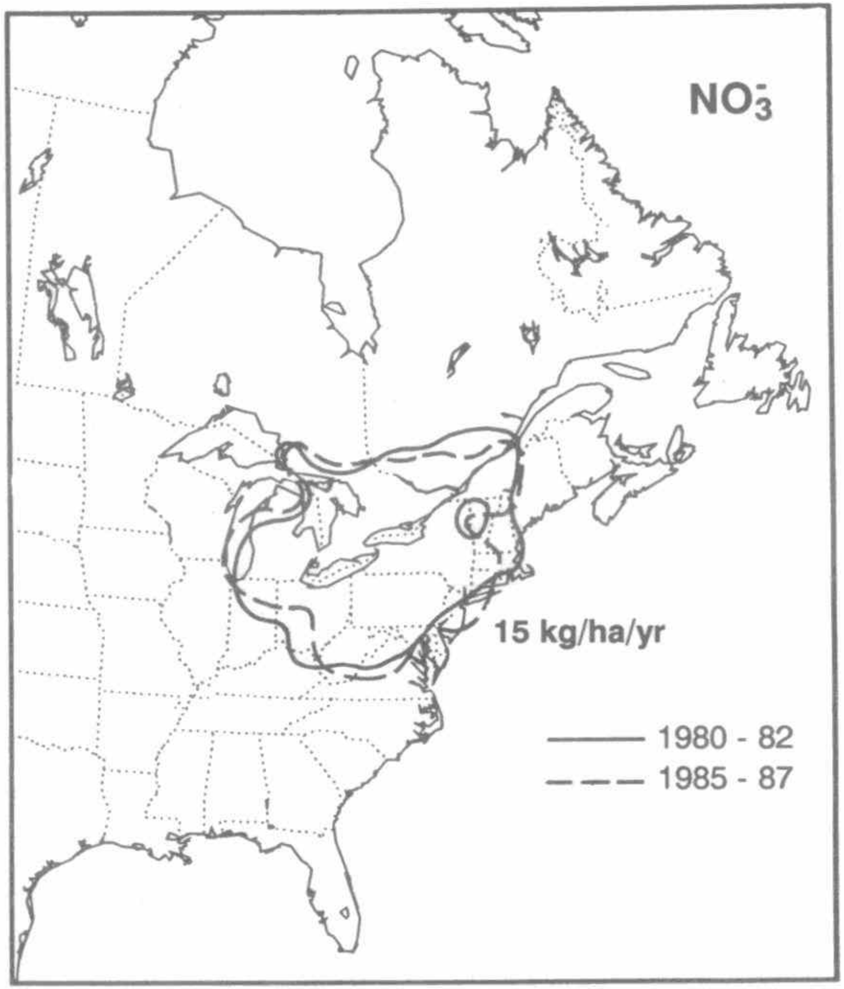


Figure 1.4.2: Superposition of the 15 kg/ha/yr nitrate deposition isopleths for the periods 1980-82 and 1985-87.

% Difference Between 3-Year Mean (1980-82, 1985-87) Excess $SO_4^=$ Concentrations

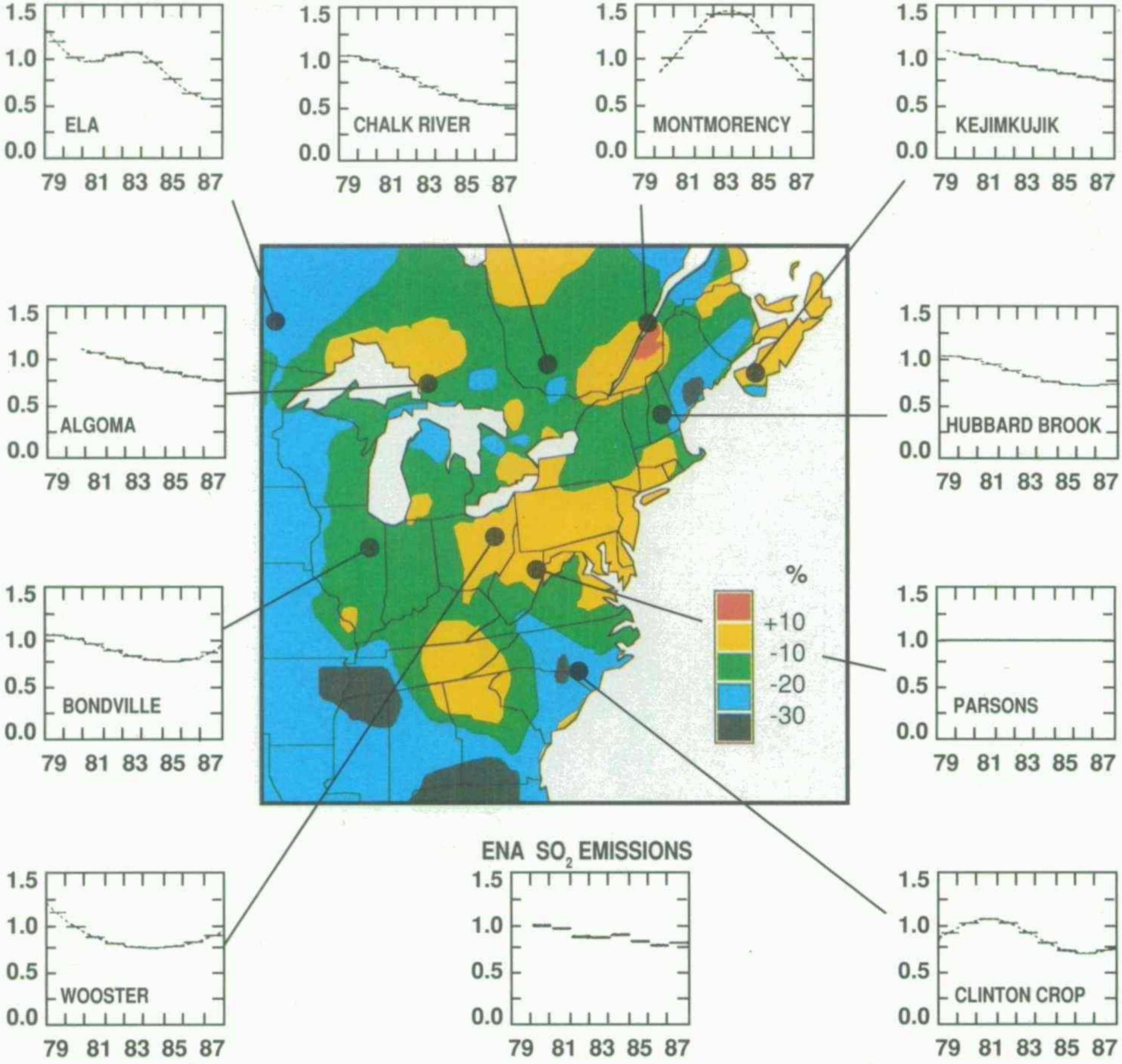


Figure 1.4.3 The central map shows the percentage change in the precipitation-weighted mean concentration of sulphate between the periods 1980-82 and 1985-1987. Underneath the figure is the time change of SO_2 emissions, compared (normalized) with 1980 emission levels, for Eastern North America. There was a 12.5% decline in emissions from the period 1980-82 to the period 1985-87. Surrounding the central map are time trends from 1979 to 1987, compared (normalized) with 1980 levels, of the weekly-average sulphate in precipitation concentrations at selected monitoring stations.

% Difference Between 3-Year Mean (1980-82, 1985-87) NO_3^- Concentrations

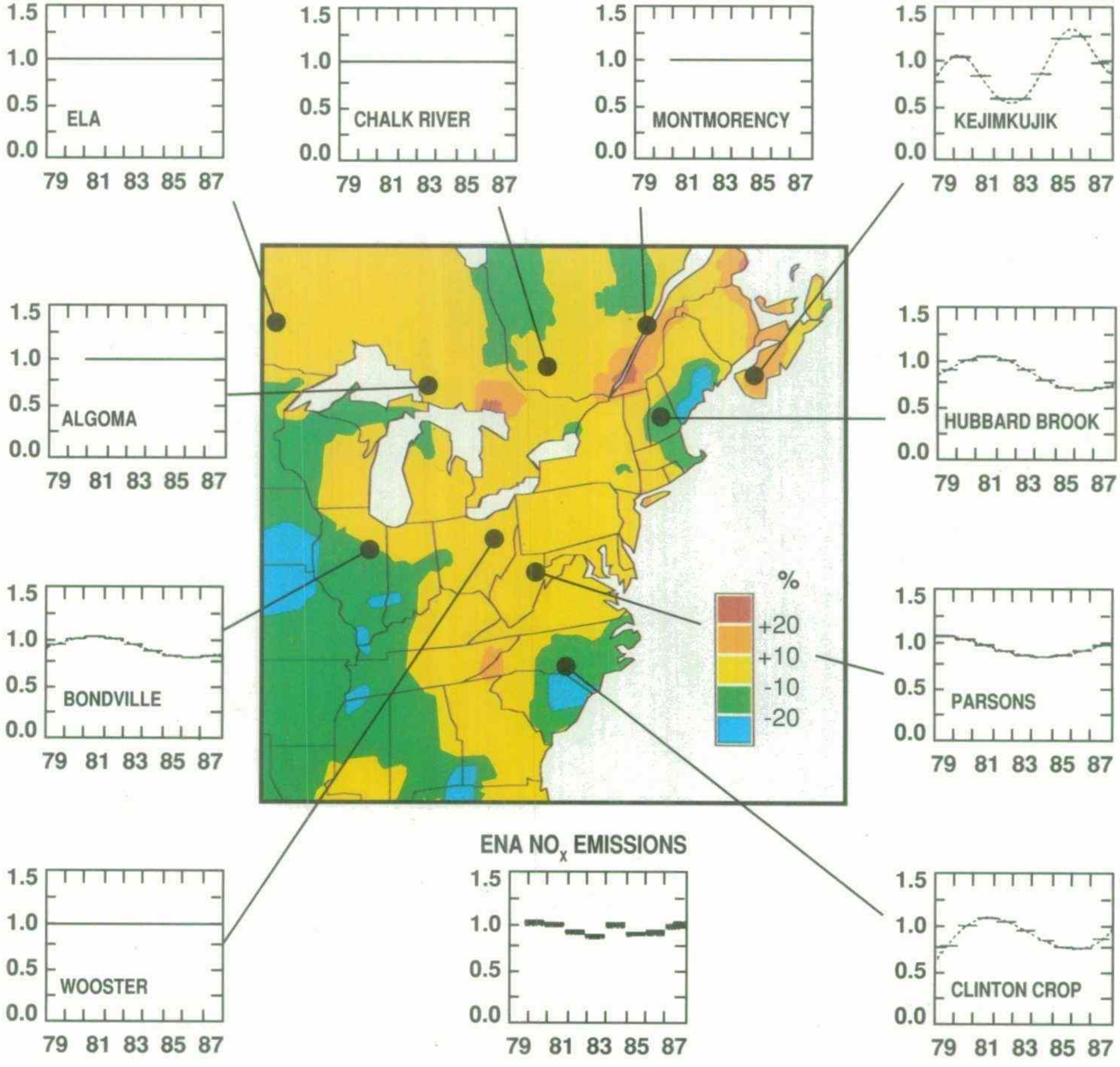


Figure 1.4.4 The central map shows the percentage change in the precipitation-weighted mean concentration of nitrate between the periods 1980-82 and 1985-87. Over most of the area there was less than a 10% change between 1980-82 and 1985-87. This is consistent with the overall small change in emissions between the two periods (see graph below central map). Surrounding the central map are time trends from 1979 to 1987, compared (normalized) with 1980 levels, of the weekly-average nitrate in precipitation concentrations at selected monitoring sites.

Emissions and deposition information alone does not allow one to quantify the contribution of a particular source area to the acid deposition at a specific receptor area. However, some inferences can be made in this regard with the complementary use of air mass trajectory techniques and the analysis of specific compounds known to have specific sources. These analyses reconfirm earlier estimates that 50 percent or more of the acid deposited in eastern Canada is due to U.S. sources.

Sulphate deposition in western Canada is generally less than 10 kg/ha/yr. Levels of wet sulphate deposition greater than 10 kg/ha/yr occur only in southwestern British Columbia and in southern Alberta and Saskatchewan. With the exception of southwestern British Columbia, these higher values can be attributed to natural sources such as sea salt and terrestrial dust.

There are serious ground level ozone problems in the lower Fraser Valley (B.C.), the Windsor-Quebec Corridor and the Maritime provinces. The only rural sites with sufficient records for trends analysis are in southern Ontario. There were no significant trends in ground-level atmospheric concentrations of ozone in southern Ontario between 1979 and 1988, although year to year concentrations vary greatly due to meteorological conditions. This is consistent with the small changes in NO_x emissions during this period in eastern North America. The application of air mass trajectory analysis to these observations demonstrates the importance of emission areas to the south as sources of episodic ozone problems in southern Ontario.

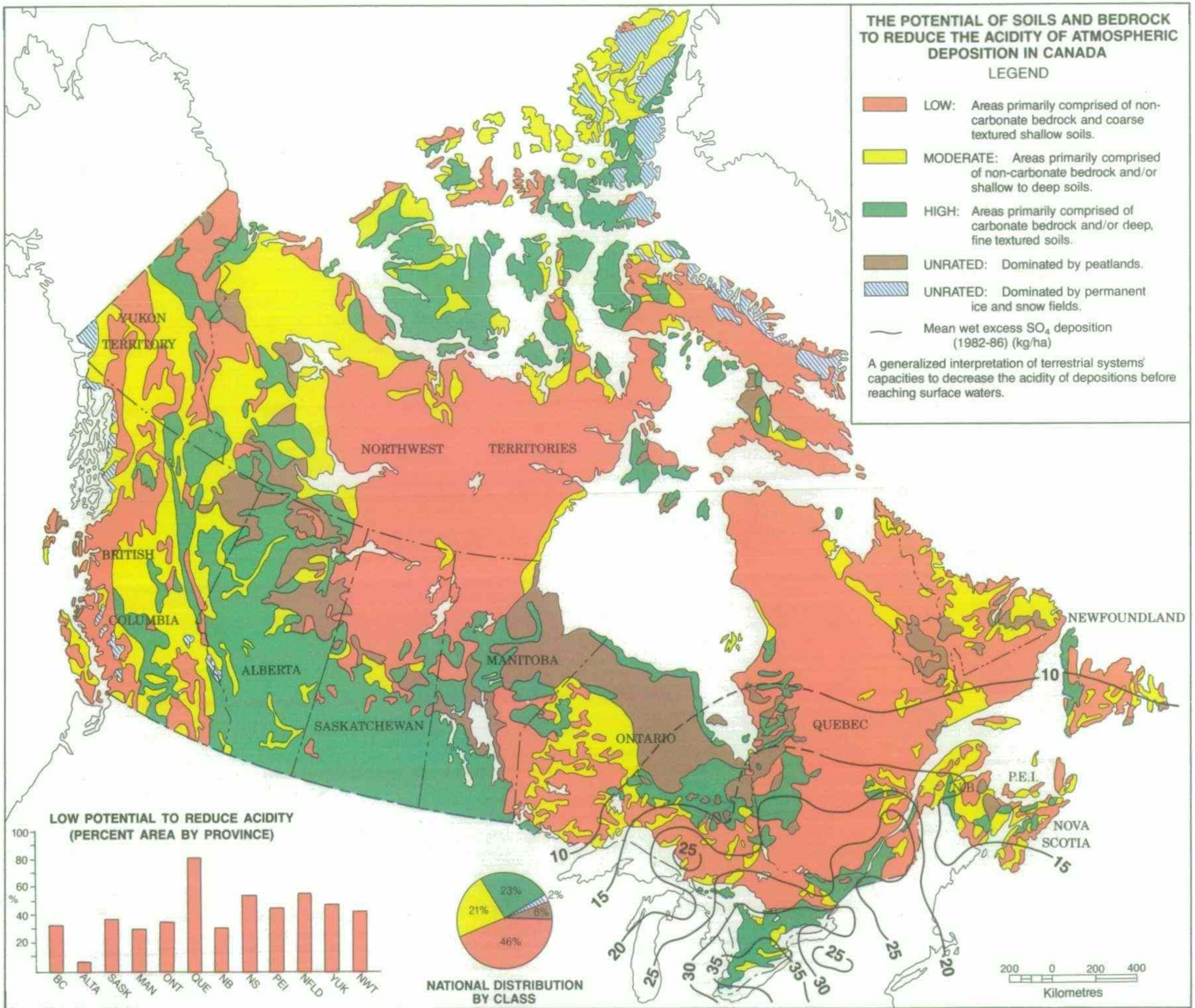
1.4.2 AQUATIC EFFECTS

Forty-three percent of Canada's land area is sensitive to acidic deposition [see Figure 1.4.5]. Sensitive terrain generally has non-carbonate bedrock and coarsely-textured, shallow surface soil deposits. These characteristics are typical of the Canadian Shield. The coincidence of sensitive terrain and acidic deposition defines the damage area of concern for aquatic effects. In eastern Canada these conditions occur in an area east of the Manitoba-Ontario border and roughly south of James Bay (latitude 52° N).

Canada's water resource is immense. An inventory of lakes within an area slightly smaller than the region of concern described above (i.e., bounded by 90 degrees west longitude) found almost 800,000 water bodies greater than 0.18 hectares in area. A special data base has been compiled that contains physical and chemical information for 8,505 lakes across eastern Canada.

A lake is defined as acidic when its buffering capacity (acid neutralizing capacity) is less than or equal to zero. Analyses of the survey data indicate that in eastern Canada there are probably more than 31,000 acidic lakes greater than 0.18 hectares in size and 14,000 acidic lakes greater than 1 hectare in size. Except for regions containing large SO_2 emitters (e.g. Sudbury and Noranda), the Atlantic provinces contain the highest proportion

Figure 1.4.5



ENVIRONMENT CANADA, INLAND WATERS / LANDS DIRECTORATE

of acidic lakes which reflects their greater sensitivity. The regional acidification of eastern Canadian lakes is primarily due to the deposition of atmospheric sulphate rather than to nitrogen deposition or to natural acidifying agents, such as organic acids or sulphide minerals in the bedrock. Acidification arising from land use changes is not considered to be important.

Terrain in western and northern Canada exhibits a broad range of sensitivity to acid deposition. The most sensitive areas coincide with the geological formations of the Canadian Shield (Manitoba, Saskatchewan, Alberta, Northwest Territories), peatlands (Alberta) or silicate bedrock in the coastal range and islands of British Columbia. The limited amount of lake survey data available in western and northern Canada confirms this interpretation. It is likely that the current low levels of acid deposition in western Canada have not significantly altered water chemistry in the region although there are a few occurrences of acidification related to local influences.

Apart from the long-term acidification of waters, temporary episodes of acidification may also produce conditions that are lethal to aquatic biota. Storage of acids within the winter snowpack can lead to the release of exceptionally high concentrations of sulphate during early melt stages that may cause short-term acidification of surface waters. Acidification episodes can also be caused by temporary storage of sulphate in the catchment, particularly in wetlands, during dry seasons. Release of sulphate at the onset of the next period of wet weather causes short term acidification of the runoff water.

Groundwater makes up a significant proportion of all water used in Canada and, in many locations, is the primary source of domestic water supply. At the few sites where intensive studies have been conducted, near-surface ground water above the water table is influenced by precipitation chemistry and may experience episodic pH depressions during periods of heavy precipitation. Groundwater below the water table, where domestic supplies are generally drawn from, shows little evidence of acidification although this may not remain the case if acid deposition continues in the long term.

The role of nitrogen in the acidification of surface and subsurface waters is more complicated than that of sulphur since there are two major inorganic species involved, nitrate and ammonium, and both are more biologically active than sulphate, the principal sulphur species. Nitrate concentrations in Canadian lakes are low, and thus acidification by nitrogen deposition is of minor consequence at this time. However, some isolated occurrences of high concentrations have been recorded and there is concern that nitrate may be of greater importance in the future, particularly since nitrate deposition has remained constant over the last decade rather than decreasing like sulphate.

Microfossils of acid sensitive species buried in lake sediments have been used to infer historical changes in water pH. Nine of the 36 lakes studied have experienced pH declines over the last 100-150 years that are attributed to acidic deposition. These lakes occur in all regions of eastern Canada. Studies have also documented both pH declines

during the past 50-100 years caused by nearby smelter emissions, and recent pH increases resulting from reduced emissions. Comparable paleolimnological studies have found no evidence of pH declines in North American lakes that receive low deposition.

Reliable chemical records, approximately a decade long, now exist for a few acid sensitive eastern Canadian lakes and streams. Some waters such as those near Sudbury and Sault Ste. Marie appear to be very responsive, exhibiting improvements in water chemistry during the 1980s that reflect decreases in acidic deposition. Other lakes have not yet responded, probably as a result of the temporary storage and release of acids in the terrestrial watershed, particulary in wetlands.

Over the past ten years, scientific understanding of the effects of acid deposition on aquatic biota has expanded greatly. There is now conclusive evidence that acidification causes adverse effects on many aquatic organisms. The total number of species of fish and other classes of aquatic biota starts to decrease at pH less than 6.0 [see Table 1.4.1] and there is an accelerating continuum of losses as pH declines further. Algal mats develop along the shoreline of many lakes at pH less than 5.8. These mats are aesthetically unpleasing and can disrupt fish spawning beds. Some important sport fish can be lost from lakes when the pH is less than 5.6, while species such as Atlantic salmon and brook trout can survive until pH drops to less than 5.1. Many amphibian species that breed in temporary ponds, which are particularly vulnerable to acidification due to their low alkalinity, are adversely affected by pond water with pH less than 4.5. Most effects of acidification on wetland birds occur through changes in quantity and quality of their food supply. However, some species have lower reproductive success in acidified lakes and streams. The important conclusion that has been drawn is that a pH of at least 6.0 must be maintained to ensure the continued presence of fish and most other important biota in aquatic ecosystems.

The estimated number of lakes in Ontario that have either lost their sport fish populations or have residual non-reproducing populations are: lake trout - 119, brook trout - 43, smallmouth bass - 52 and walleye - 14. A 23 percent decrease in fish species richness has occurred in southwestern Quebec since the onset of anthropogenic acidification. One-third of the available Atlantic salmon habitat in Nova Scotia has been lost to acidification since 1950. This is a loss to the salmon fisheries of about 9,000 - 14,000 fish per year and is almost equal to the current annual catch.

The long-range transport of acidic substances is also linked with increased exposures of aquatic biota to toxic metals. This occurs in three ways: anthropogenic emitters of sulphur also discharge large quantities of trace metals; metals may be leached in greater quantities from catchments due to acidification of shallow ground waters; and bioaccumulation of some metals may be increased in acidified aquatic environments. Elevated dietary levels are a potential health threat to mammals and birds which regularly consume aquatic biota. Although direct evidence does not yet exist, there is indirect evidence of a relationship between surface water acidification and high levels of mercury

observed in many large sport fish in Ontario and of cadmium in eastern Canadian moose. These metals have implications for human health and have resulted in restrictions on human consumption of fish and moose.

Table 1.4.1 Examples of losses or appearances (denoted by *) of aquatic species in Canadian waters for 3 pH classes between pH 6.0 and 4.0. In general, fewer fish, algae, zooplankton, and zoobenthos species are present as pH decreases.

	pH Range		
Taxa	6.0 - 5.6	5.5 - 5.1	5.0 - 4.0
Fishes	common shiner fathead minnow slimy sculpin blacknose shiner bluntnose minnow	lake trout white sucker walleye smallmouth bass lake whitefish	yellow perch brook trout Atlantic salmon
Algae	odiferous algae* shoreline algal mats*		
Zooplankton	water flea	2 copepod species	
Zoobenthos	3 crayfish species freshwater shrimp 1 snail species 7 mayfly species	1 amphipod species 5 leech species 3 mayfly species	4 mayfly species
Amphibians			many frog, toad, and salamander species
Wetland Birds	common loon	osprey ring-necked duck	tree swallow

Little is known about the speed of biological recovery following decreases in acid deposition except that it is obviously slower than changes in water chemistry. Work in the lakes near Sudbury and at the Experimental Lakes Area in northwestern Ontario has shown that by reversing acidification successful reproduction can occur in formerly non-reproducing fish populations.

1.4.3 TERRESTRIAL EFFECTS

The effect of LRTAP on the terrestrial environment involves the effects of acid deposition and ozone on forests, agriculture, soils and wildlife. Of concern is the extent of these resources at risk and the magnitude of observed effects.

The existing wet sulphate target loading for the Canadian Acid Rain Control Program of 20 kg/ha/yr was developed to protect moderately sensitive aquatic systems. No data were available to develop a target loading for terrestrial systems. However, if this value were used as an indicator for potential terrestrial damage, then approximately 15 million hectares of hardwood and mixed wood forests in eastern Canada are at risk [see Figure 1.4.6]. Nitrate deposition follows a similar pattern as sulphate deposition in eastern Canada [see Figure 1.4.7]. While acid deposition is much reduced in western Canada, there is significant deposition in the lower mainland of British Columbia, accompanied by elevated ozone levels. It is estimated that 2-3 million hectares of forest in British Columbia are exposed to these pollutants.

In Canada, most of the forests exposed to high levels of acid deposition and ozone are those close to populated areas. These forests are some of the most productive in the country and the most heavily utilized. Typical uses include recreation, tourism, wildlife habitat, aesthetics and forest product activities (woodlots, maple syrup, quality softwood and hardwood lumber).

There is general agreement that the current episode of maple decline in Canada is more severe and more extensive than those which have occurred in the past. Although no evidence currently exists for a direct (foliar/airborne) or single component causal role for acidic deposition or ozone in any of the current tree declines in eastern Canada, studies conducted in Ontario and Quebec indicate that acidic deposition and other long range transported air pollutants may be indirect (soil/nutrient) or contributing (pre-disposing) factors in sugar maple decline. The role and importance of these additional stresses on trees already under natural stresses such as climatic extremes (drought, temperature), or attack by insects and disease, remains unknown but must be viewed with concern.

Symptoms of maple decline and tree mortality have continued to increase in severity and extent. Other species in the same stands have also been affected. In many areas subject to acidic deposition and experiencing tree decline, soils have become deficient in several essential nutrients. Nutrition research has indicated that soil chemistry is an

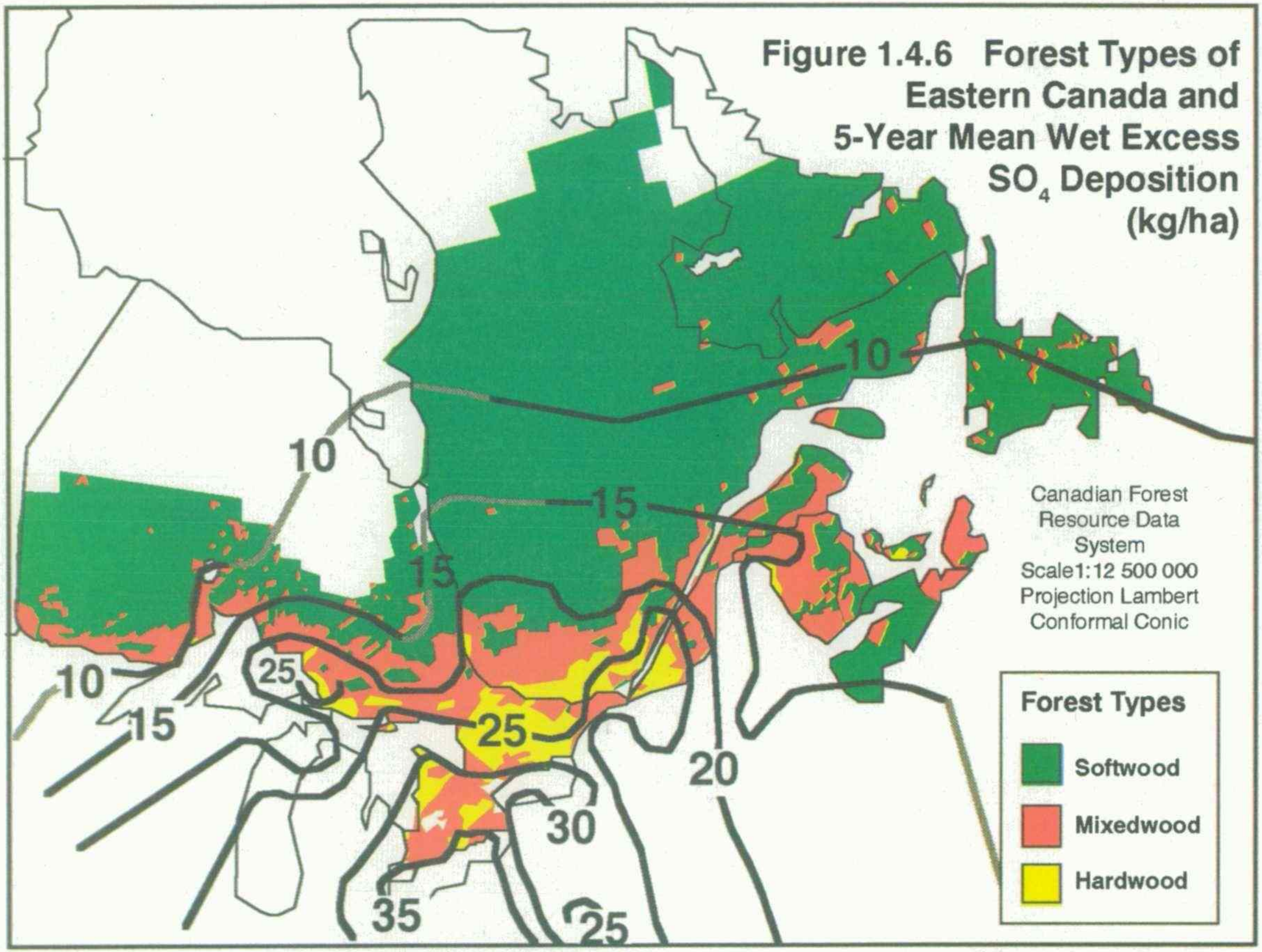
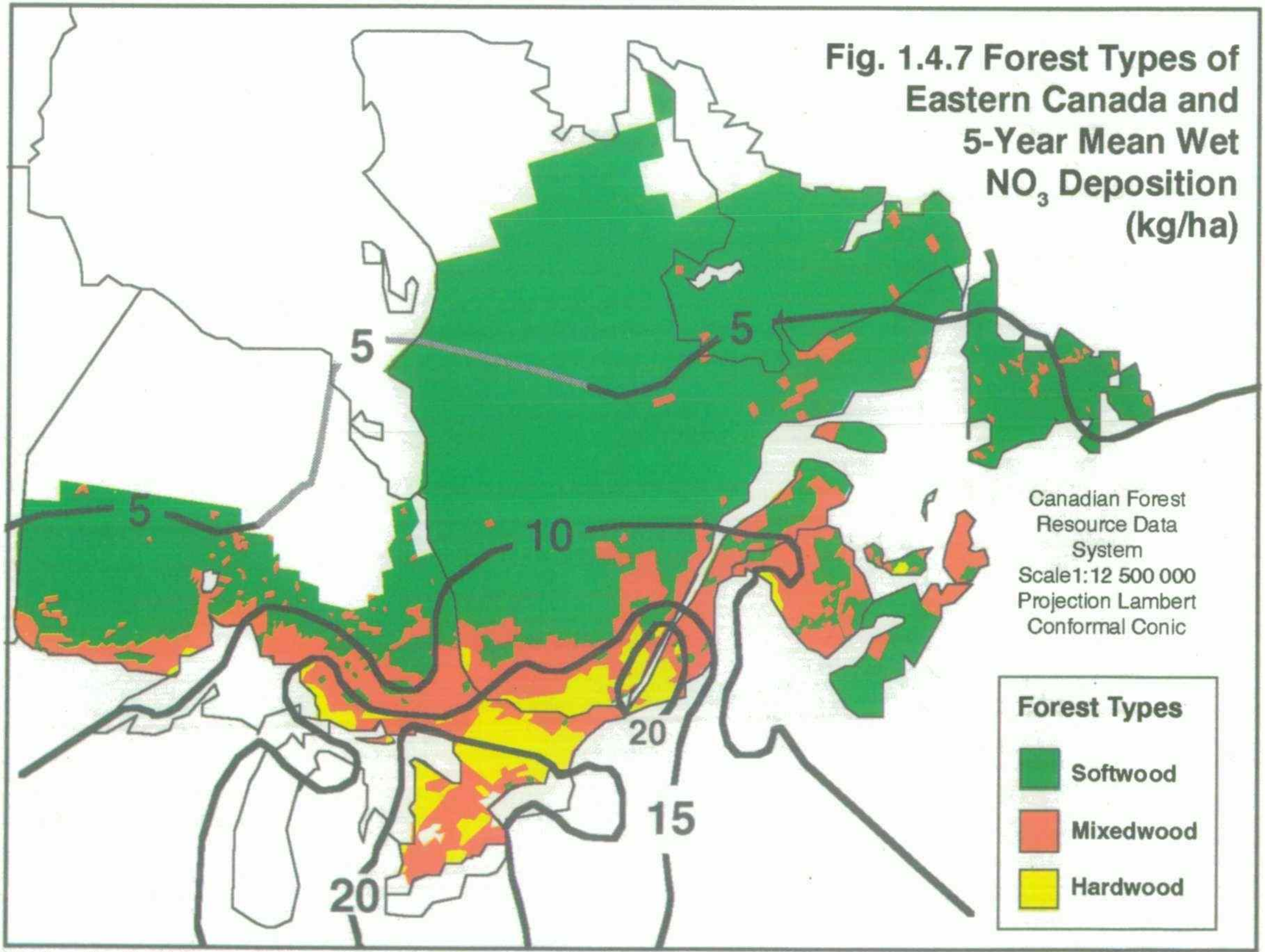


Figure 1.4.6 Forest Types of Eastern Canada and 5-Year Mean Wet Excess SO_4 Deposition (kg/ha)

Produced by the Petawawa National Forestry Institute, November 1990



Produced by the Petawawa National Forestry Institute, November 1990

important factor in the decline syndrome and that in the short term, forest fertilization can provide an effective ameliorative treatment.

Dendrochronology data from Ontario sugar maple studies also indicate that significant growth reductions have occurred in declining as well as outwardly healthy trees since the mid-1940s to mid-1950s in regions experiencing moderate to high levels of acidic deposition and ozone.

Research in New Brunswick has circumstantially linked the white birch deterioration along the Bay of Fundy coast with exposure to acidic marine fog.

The impact of ozone on agricultural crops has been clearly established. Foliar injury to many sensitive crops has been observed in New Brunswick, Quebec, Ontario and British Columbia at ozone levels which are at, and even below, the national 1 hour objective of 82 ppb. Significant ozone-related yield losses in sensitive crops have been documented in several studies in Ontario and British Columbia. In Ontario, annual yield losses in 19 species are estimated to range from 1 to 10 percent each year. Estimates of increased crop and ornamental productivity, if the 1 hour Ontario ozone objective of 80 ppb was met, range from $17 to $70 million annually, or up to about 4 percent of total annual sales of $1.9 billion.

LRTAP may affect terrestrial wildlife through the loss of habitat, from changes in food availability and/or quality, or as a result of a chronic accumulation of toxic pollutants in their tissues. Defoliation in declining maple stands, in Quebec, has led to a decreased abundance of birds that rely on the canopy for food and shelter and an increased abundance of species that prefer ground cover vegetation. Lichens and some other food sources of moose and deer have been found to accumulate toxic metals when grown on poorly buffered soils in acid-sensitive areas of Ontario. Food chain effects have resulted in the accumulation of cadmium in the livers and kidneys of moose and deer in certain areas such that these organs have been declared unfit for human consumption.

1.4.4 HUMAN HEALTH EFFECTS

There is a broad range of health responses associated with exposure to air pollution ranging from the immediate such as aggravation of asthma and increased hospital admissions to long term responses such as chronic lung disease, bronchitis and accelerated aging of the lung. Subtle changes in respiratory health can be ascertained using indicators such as decreases in lung function, decreases in the rates at which inhaled particles are removed from the upper respiratory tract surfaces, and alterations in biochemical and immunological indices.

The two components of LRTAP which most likely affect human health in a direct way are ozone and acid aerosols, including sulphuric acid. Evidence from animal studies and preliminary evidence from human studies suggest that health effects are due to acid

aerosol exposure. Acid aerosols are constituent elements of pollutants present in the atmosphere and with respect to health effects are difficult to separate into distinct entities from the pollutant mixture (i.e. different compounds contribute to the total acidity $[H^+]$ present in the atmosphere). Also, interactions of acid aerosols with other pollutants and the spatial-temporal dynamics of exposure to acid aerosols with or without other airborne constituents are not completely understood.

In general, the highest aerosol acidity concentrations measured to date have been in regions that have the highest density of SO_2 emissions - the midwestern United States and southeastern Canada. Acid aerosols are difficult to measure and hence have not been monitored routinely in Canada. What few measurements exist for Canada show the highest levels occurring in southwestern Ontario and Nova Scotia with the maximum hourly sulphuric acid level of approximately 50 $\mu g/m^3$ observed on the north shore of Lake Erie. Maximum exposures (concentration × time) in southern Ontario are equivalent, on a daily basis, to levels that have produced chronic bronchitis-like changes in laboratory animals.

In contrast to aerosol acidity, there is a better data base on surface ozone levels in Canada, particularly in urban areas. Studies have indicated that, in addition to locally produced ozone, there can be appreciable amounts arising from long range transport. The Canadian 1-hour maximum acceptable ozone concentration of 82 parts per billion is often exceeded in the summer months along the Windsor-Quebec City corridor, and occasionally in the Vancouver area. For several Canadian communities, current peak ambient ozone concentrations are sufficient to cause transient respiratory effects in healthy people. Furthermore, these effects are sometimes augmented by environmental variables (e.g. temperature, humidity) and/or interactions with other pollutants in the atmosphere.

A recent study in Canada observed small decrements in children's lung function which occurred during times of high air pollution. Acid levels reached a maximum of about 50 $\mu g/m^3$, and ozone levels were as high as 143 ppb. In two other Canadian studies where the respiratory health of children in a region which experiences high levels of LRTAP was compared with that of children in a region experiencing very low levels of LRTAP, an average 2 percent decrement in lung function was observed in the polluted region. Children in the more polluted area also had a higher incidence of upper respiratory infections. It is believed that the observed difference is likely due to the coexistence of acidic aerosols and other pollutants, i.e., O_3, SO_2.

Hospital admissions for respiratory conditions are indicative of trends in respiratory health in the general population. Scientists have found an association between admissions in summer for respiratory disease and daily pollution levels, and it is proposed that sulphuric acid aerosol is the pollutant most probably responsible for this association. The combination of ozone and acid may increase individual susceptibility. Subgroups within the general population (e.g. asthmatics) may have increased individual susceptibility.

Human health may also be affected by acid deposition in an indirect manner. The acidification of water supplies and soils, with subsequent mobilization of heavy metals, may increase exposure to these potentially toxic substances through drinking water and food. Of significant concern here are cadmium and mercury which may enter into food sources and result in biomagnification through the food chain to man. Currently, the most detrimental effect on drinking water from acidified supplies (such as lakes and shallow wells in acid sensitive areas) is probably the corrosion of metal plumbing systems and the subsequent release of toxic heavy metals, particularly lead. In areas of eastern Canada most sensitive to acidification, an estimated 300,000 people obtain their drinking water from unregulated sources that may be affected by acid deposition.

1.5 WHAT CHANGES CAN BE EXPECTED AS A RESULT OF FULL IMPLEMENTATION OF THE SULPHUR DIOXIDE CONTROL PROGRAMS IN THE UNITED STATES AND CANADA? WILL THESE CONTROL PROGRAMS BE SUFFICIENT TO PROTECT THE CANADIAN ENVIRONMENT?

The Eastern Canadian acid rain control program, described in Section 1.2, will reduce SO_2 emissions in the seven most easterly provinces by 50 per cent by 1994. The United States has been slower to develop legislation to control acid rain; however, amendments to the Clean Air Act to control $S0_2$ emissions were finally passed in November 1990. The analysis of the effectiveness of the Canadian and U.S. control programs offered by the RMCC in this report is based on the actual details of the SO_2 Control Program in Eastern Canada, and also on our best judgement of the distribution of the 10 million ton (9 million metric tonne) reduction in SO_2 announced by President Bush in the summer of 1989 (see Atmospheric Sciences Report Appendix G for further details). The acid rain amendments to the Clean Air Act are very similar to those first introduced by President Bush and analyzed in this report.

Three future sulphate deposition scenarios have been compared with the observed 5 year mean deposition values for 1982 to 1986. The specific scenarios are listed below:

Scenario 1. Current Conditions - Observed 5 year (1982-1986) mean excess sulphate deposition.

Scenario 2. Model projections of deposition under conditions of full implementation of the SO_2 control program in eastern Canada and U.S. SO_2 emissions equal to 1980 levels.

Scenario 3. Model projections of deposition under conditions of full implementation of the SO_2 control program in eastern Canada and a 5 million ton (4.5 million metric tonne) reduction in 1980 emissions in the U.S. (i.e. first phase of control program to be implemented by 1995, announced by President Bush in the summer of 1989).

Scenario 4. Model projections of deposition under conditions of full implementation of the SO_2 control program in eastern Canada and a 10 million ton (9 million metric tonne) reduction in 1980 emissions in the U.S. (i.e. full implementation of control program by 2000-2003, announced by President Bush in the summer of 1989).

Predicting the overall effectiveness of the Canadian and U.S. control programs in protecting the Canadian environment depends upon two primary factors: 1) our ability to quantitatively specify the relationship between emissions and deposition (i.e. source-receptor relationships) and 2) the actual protection from acidification afforded by the target load (i.e. target load/critical load relationships). These factors are discussed below.

1.5.1 SOURCE/RECEPTOR RELATIONSHIPS

Similarities in the temporal and spatial patterns of SO_2 emissions and sulphate deposition in eastern North America show that reductions in emissions lead directly to reductions in deposition. Atmospheric deposition measurements alone, however, are not sufficient to quantify the contribution of specific source areas to deposition at a particular receptor area. In order to predict specific results of an emissions control plan, a different approach is required. Mathematical models of long-range atmospheric transport currently provide our best means for establishing quantitative source/receptor relationships.

Relatively simple models were used in the mid-80s to help formulate Canada's SO_2 emission control policy. These models have been strongly criticized because of their unsubstantiated assumption of a linear relationship between the magnitude of emissions and of downwind deposition. Subsequently, much more complex "Eulerian" models containing a state-of-the-art treatment of atmospheric transport, transformation and deposition processes have been developed. Although the evaluation of these Eulerian models against field measurements is incomplete, preliminary work suggests that they perform well.

Results obtained from the Eulerian models indicate that simple, linear, long-range transport models probably overpredict the extent of wet sulphate deposition reductions to be expected after controls are imposed. However, the degree of non-linearity is not considered to be significant, given the uncertainties in the models and observations. In addition, the total (wet plus dry) deposition of sulphur responds to emission changes in a more linear fashion than wet deposition alone. Based on these results, it is concluded that simple linear models can be used for regulatory purposes for total sulphur deposition, at least on an annual basis. The Canadian target loading is expressed in terms of wet deposition alone since it can be more accurately measured than total deposition. Its derivation, however, assumed an accompanying dry deposition component that would also be reduced by a emission control program.

The Ontario Ministry of the Environment's Lagrangian long-range transport model has been used to predict wet sulphate deposition resulting from the three future deposition scenarios discussed previously. Current conditions (scenario 1) and the three future scenarios (scenarios 2-4) are shown in Figures 1.5.1-1.5.4.

1.5.2 TARGET LOAD/CRITICAL LOAD RELATIONSHIPS

What will be the resulting environmental response when the Canadian and U.S. SO_2 emission controls are put in place? Although this question concerns all ecosystem components (i.e. aquatic, terrestrial, health and materials, etc.), deposition/response relationships are best understood for the aquatic regime where calibrated models exist that relate deposition to lake acidification and biological damage. While attention has been focused on the aquatic regime, there is some justification to believe that protection of it will also result in the protection of other ecosystem components.

The target load itself when established in the early 1980s was based on aquatic effects. Loss of sport fish, which occurs at a lake pH threshold of 5.3, led to the setting of the current target for wet sulphate deposition. It was realized at the time, however, that very sensitive basins would not be protected by this loading and that further evaluation would be needed when more information was obtained. It must be noted that the design of the Canadian emission control program assumed that deposition reduction to the target level in southern Ontario and Quebec, where deposition is highest, would reduce deposition to well below 20 kg/ha/yr in the Atlantic provinces where sensitivity is greater.

Recently, research has been directed toward determining the "critical" aquatic load, i.e. the highest deposition of acidifying compounds that will not cause chemical changes leading to long-term harmful effects on the overall structure or function of the aquatic ecosystem. The critical load is therefore based on a whole ecosystem response and represents the ideal in environmental protection. Critical load information can be used, along with information on economic and social concerns, in the selection of target loads and in the design of control programs.

The current information on the effects of acid deposition on aquatic ecosystems shows that pH = 6.0 is a suitable chemical threshold for use in defining critical loads [see Table 1.4.1]. Above this pH, virtually all aquatic biota (not just sport fish as defined by the 5.3 threshold) will be protected from harm. However, some areas in eastern Canada, mainly in the Atlantic provinces, have a significant percentage of lakes with a natural pH less than or equal to 6.0. Hence, determination of critical loads in these regions is based on those lakes which are believed to have had a historical pH level of greater than 6.0.

Steady state aquatic chemistry models have been used to predict a deposition value that will maintain at least 95 percent of the lakes in a region (grouping or aggregate of lakes) at a pH of 6.0 or higher. This may be considered a reasonable approximation of a

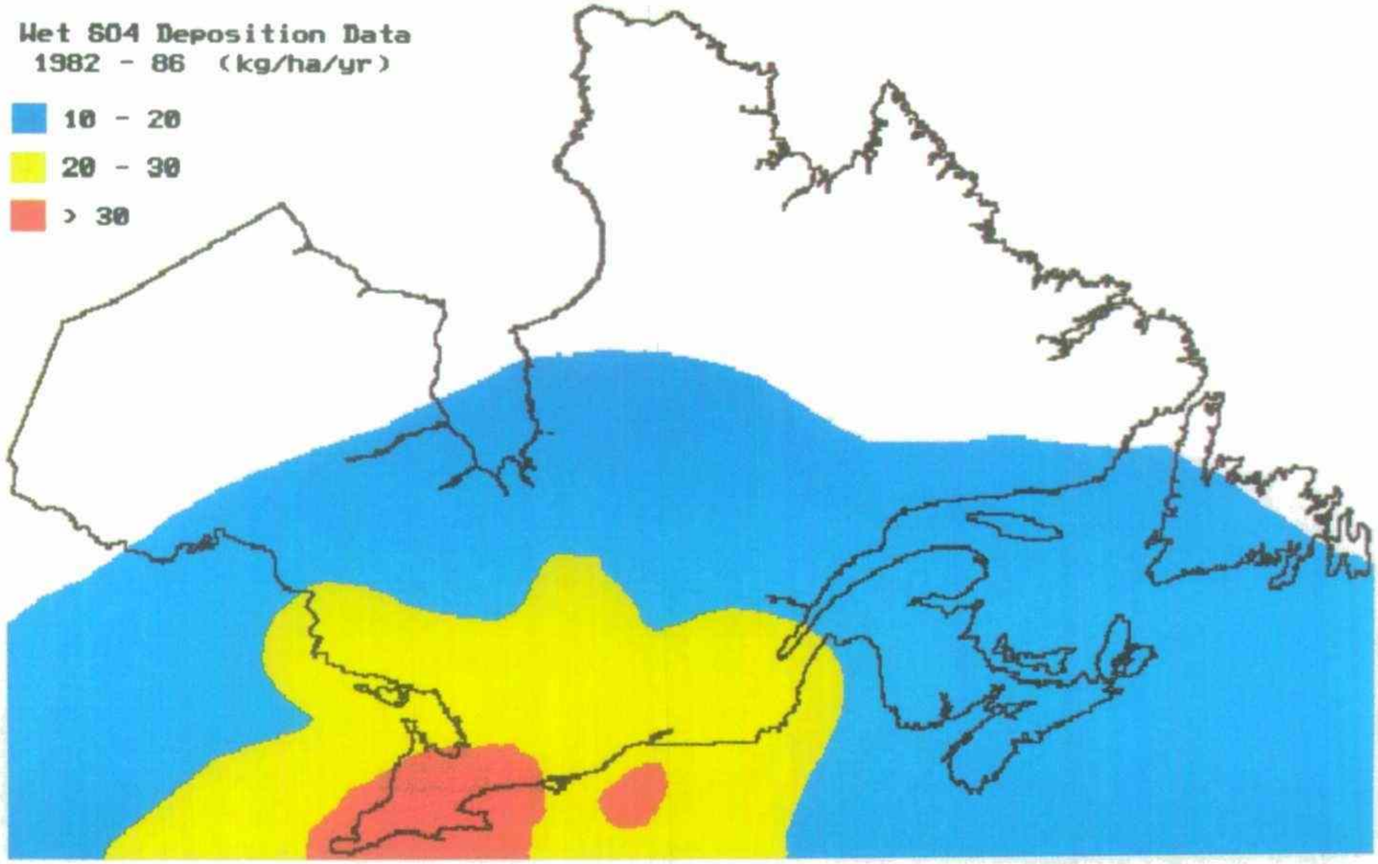


Figure 1.5.1 Scenario 1 - Current Conditions. Observed 5 year (1982-86) mean excess sulphate deposition.

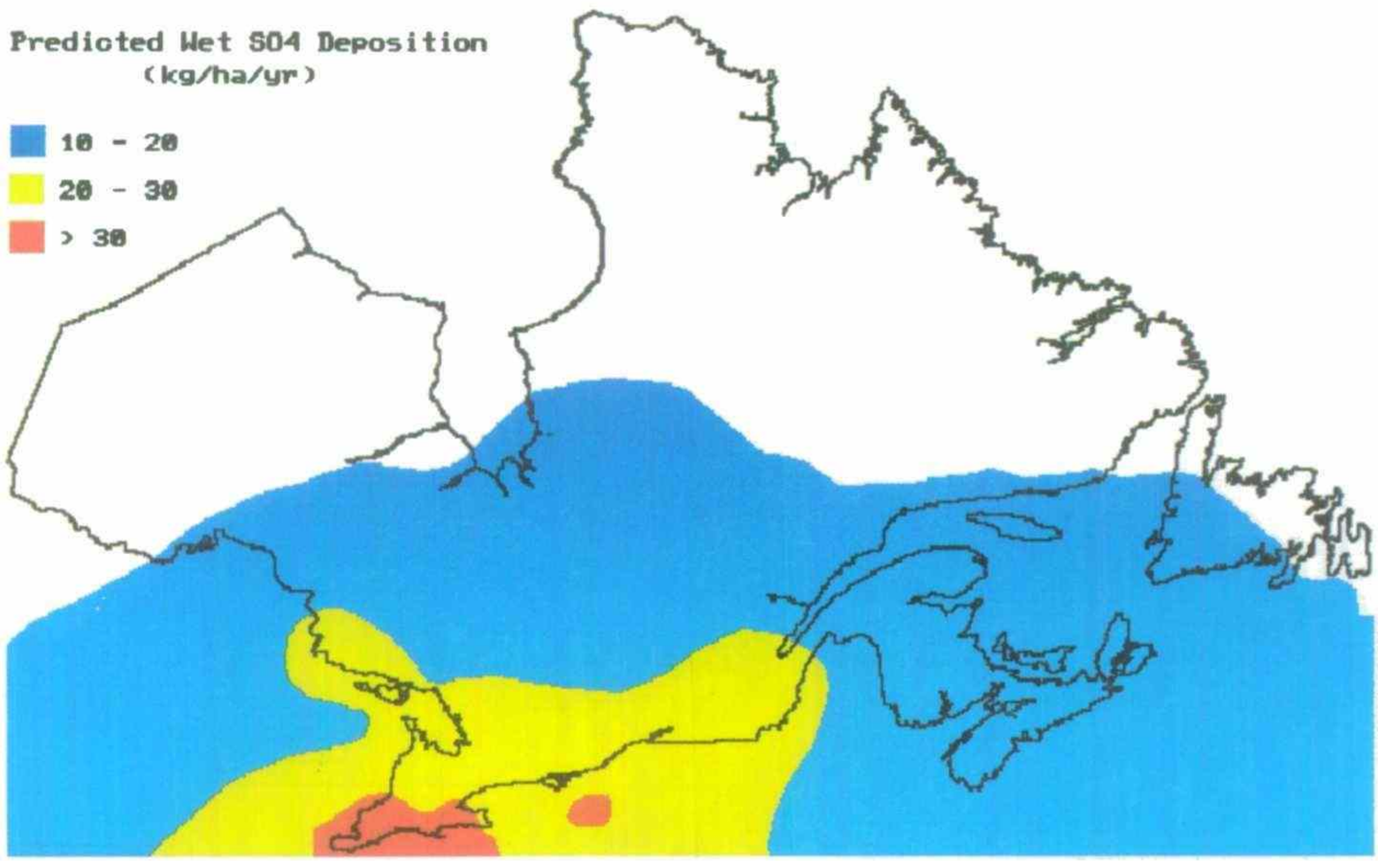


Figure 1.5.2 Scenario 2 - Model projections of deposition under conditions of full implementation of the SO_2 control program in eastern Canada and U.S. SO_2 emissions equal to 1980 levels.

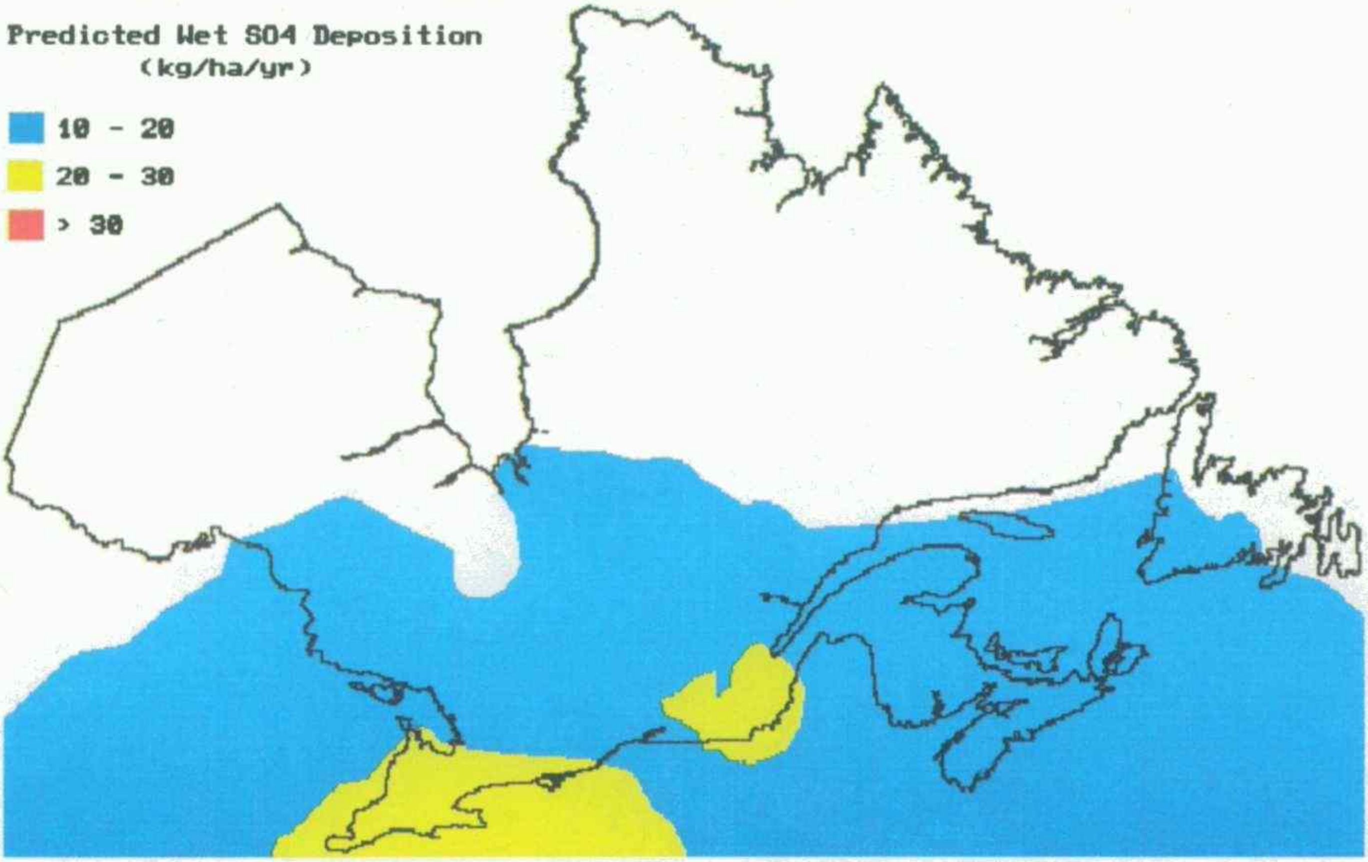


Figure 1.5.3 Scenario 3 - Model projections of deposition under conditions of full implementation of the SO_2 control program in eastern Canada and a 5 million ton (4.5 million metric tonne) reduction in 1980 emissions in the U.S.

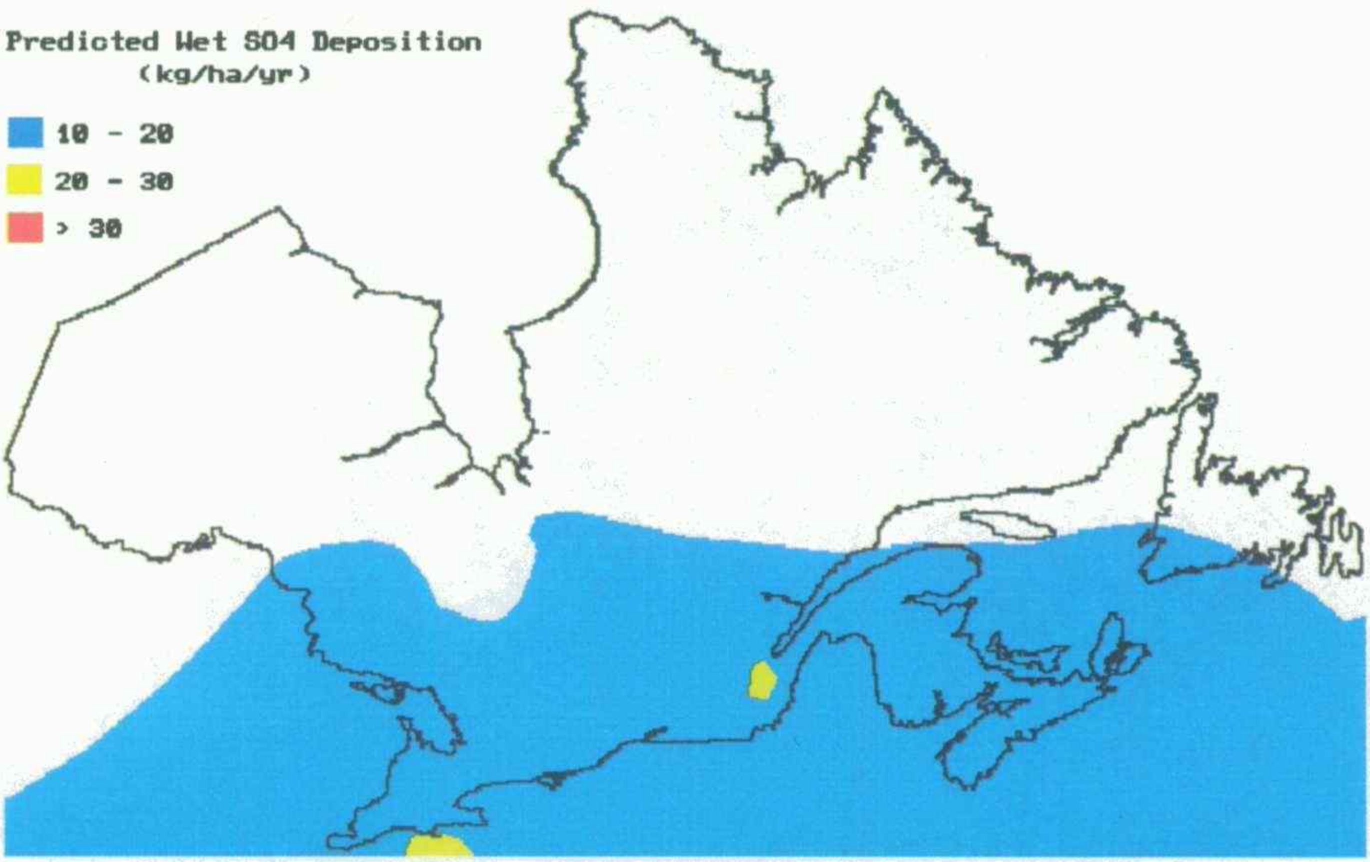


Figure 1.5.4 Scenario 4 - Model projections of deposition under conditions of full implementation of the SO_2 control program in eastern Canada and a 10 million ton (9 million metric tonne) reduction in 1980 emissions in the U.S.

region's critical load. These values range from less than 8 to more than 20 kg/ha/yr wet SO_4 [see Figure 1.5.5]. Variability in terrain sensitivity means that specification of a single critical load for eastern Canada is inappropriate. The Atlantic provinces, Labrador, and eastern Quebec generally have very low critical loads of less than 8 kg/ha/yr that are close to the background deposition. Sub-regions in southwestern Quebec have critical loads of 9 to more than 20 kg/ha/yr while in Ontario they vary from 8 to more than 20 kg/ha/yr.

The aquatic effects associated with the four scenarios of sulphate deposition have been evaluated using chemistry models. The percentage of lakes remaining with conditions of pH less than 6.0 and pH less than 5.3 for the control scenarios are shown in Figures 1.5.6 and 1.5.7. The pH 6.0 criterion has been to infer the critical loads (values that will fully protect the environment) while the pH 5.3 value represents a level where elimination of sport fish is likely to occur and was used to derive the existing 20 kg/ha/yr target load. The models predict that implementation of the Canadian SO_2 control program will produce improvements in lake chemistry mainly in Ontario and Quebec. For example, the Sudbury-Noranda region (Aggregate 19) has 18 percent of modelled lakes with pH less than 6 under scenario 2, as compared to 38 percent under the current scenario. The proposed U.S. reduction will benefit this region also; the percentage of modelled lakes with pH less than 6 becomes 13 percent for Scenario 3 and 10 percent for Scenario 4. Applying these modelled percentages to all of the approximately 45,000 lakes greater than 0.18 hectare in size within this region, the number of lakes with pH less than 6.0 is estimated to be greater than 17,000, 8,000, 5,000, and 4,000 for Scenarios 1 through 4 respectively.

The atmospheric models do not predict a very large decrease in deposition in the Atlantic regions in spite of the overall 50 percent decrease in upwind emissions and transboundary flow. Correspondingly, the aquatic models do not predict much improvement in aquatic conditions in the very sensitive areas of southern Nova Scotia and New Brunswick. It is estimated that in New Brunswick, Nova Scotia, P.E.I. and insular Newfoundland 47,000 lakes greater than 0.18 hectare and 19,000 greater than 1 hectare will have $pH < 6$ after implementation of the U.S. and Canadian control programs.

Like water pH, improvement to the aquatic biota is also predicted for most areas as a result of emission reductions [see Figure 1.5.8]. For example, 21 percent of modelled lakes in the Laurentide region of Quebec (Aggregate 14) have more than a 10 percent reduction in fish species richness under current conditions (Scenario 1). A reduction in "richness" means a loss of the number of fish species present in a lake, and a 10 percent reduction is termed the "fish damage level". The percentage of lakes exceeding the fish damage level will be reduced to 14, 11, and 8 percent of the lakes under Scenarios 2, 3 and 4, respectively.

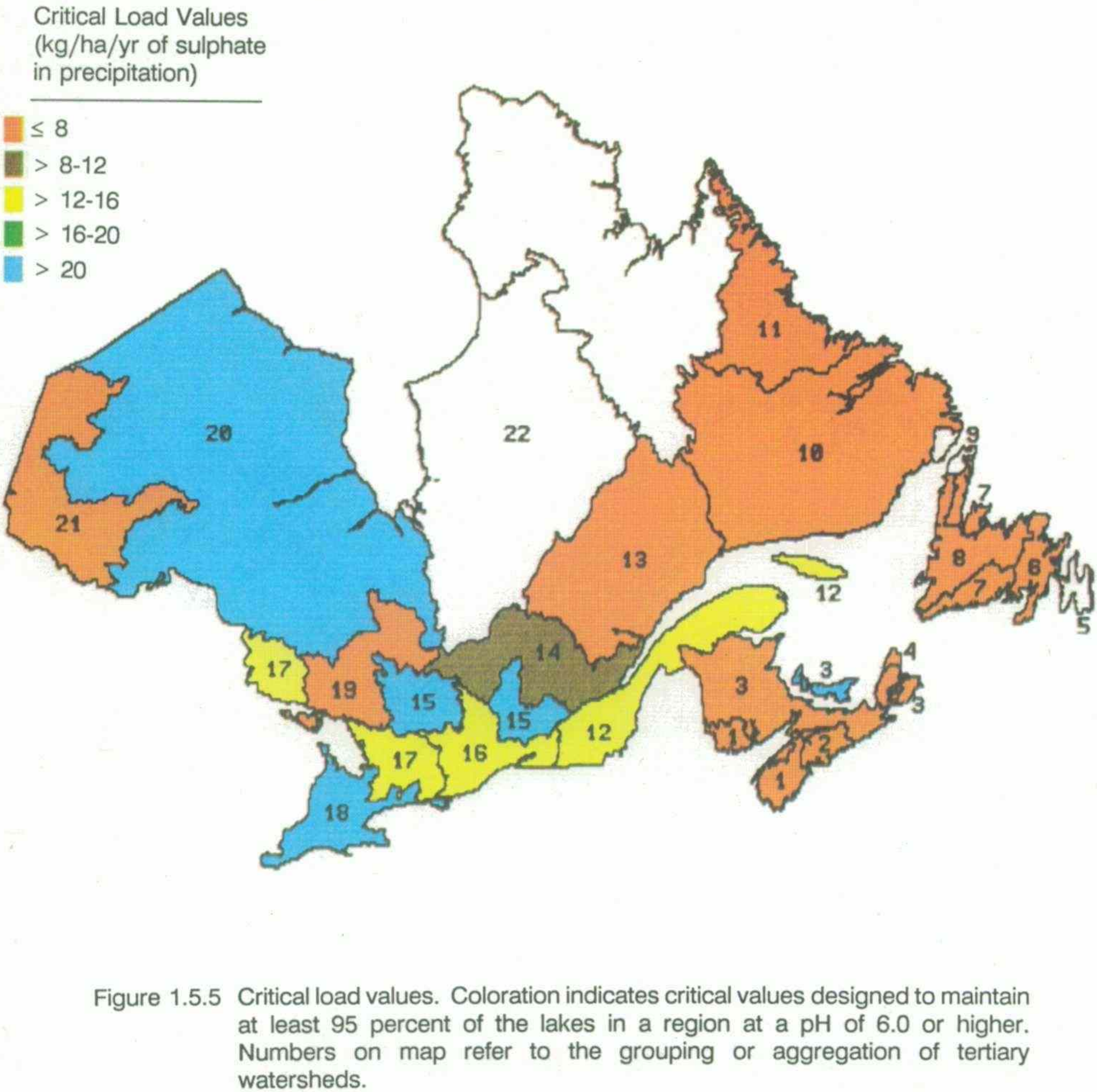
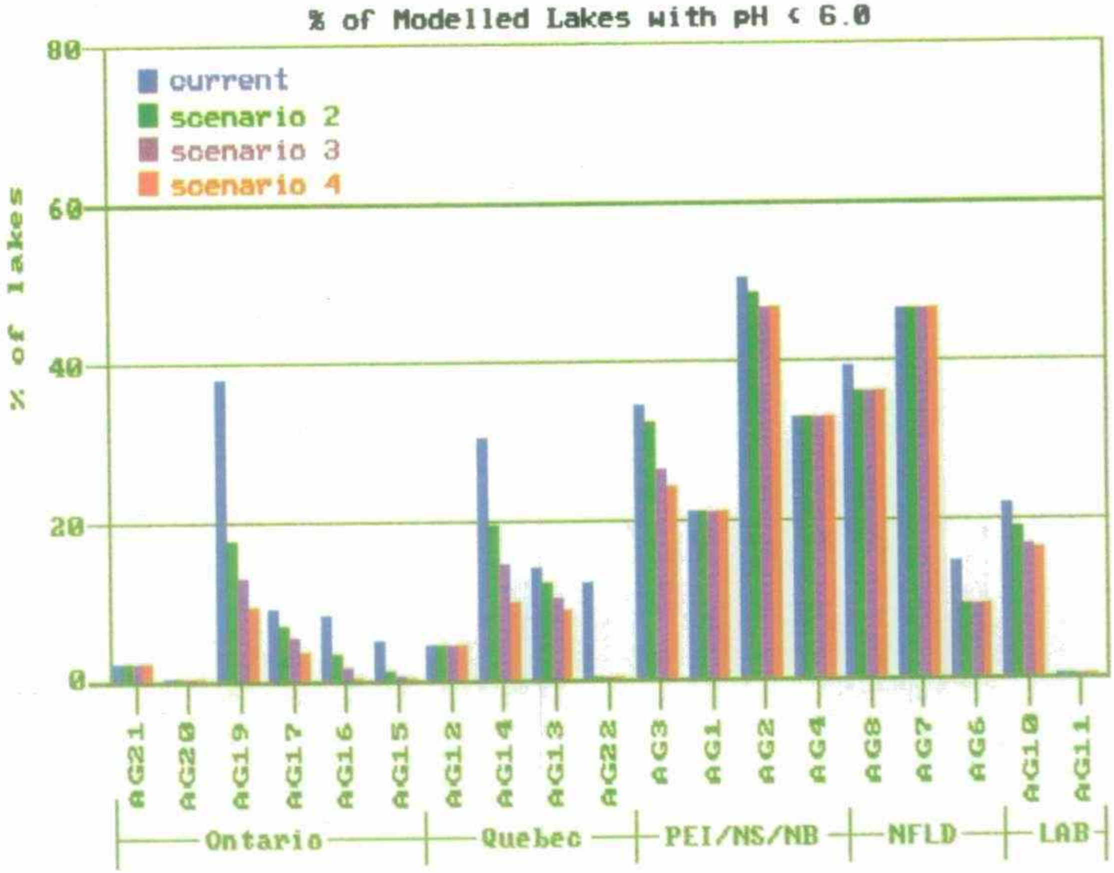
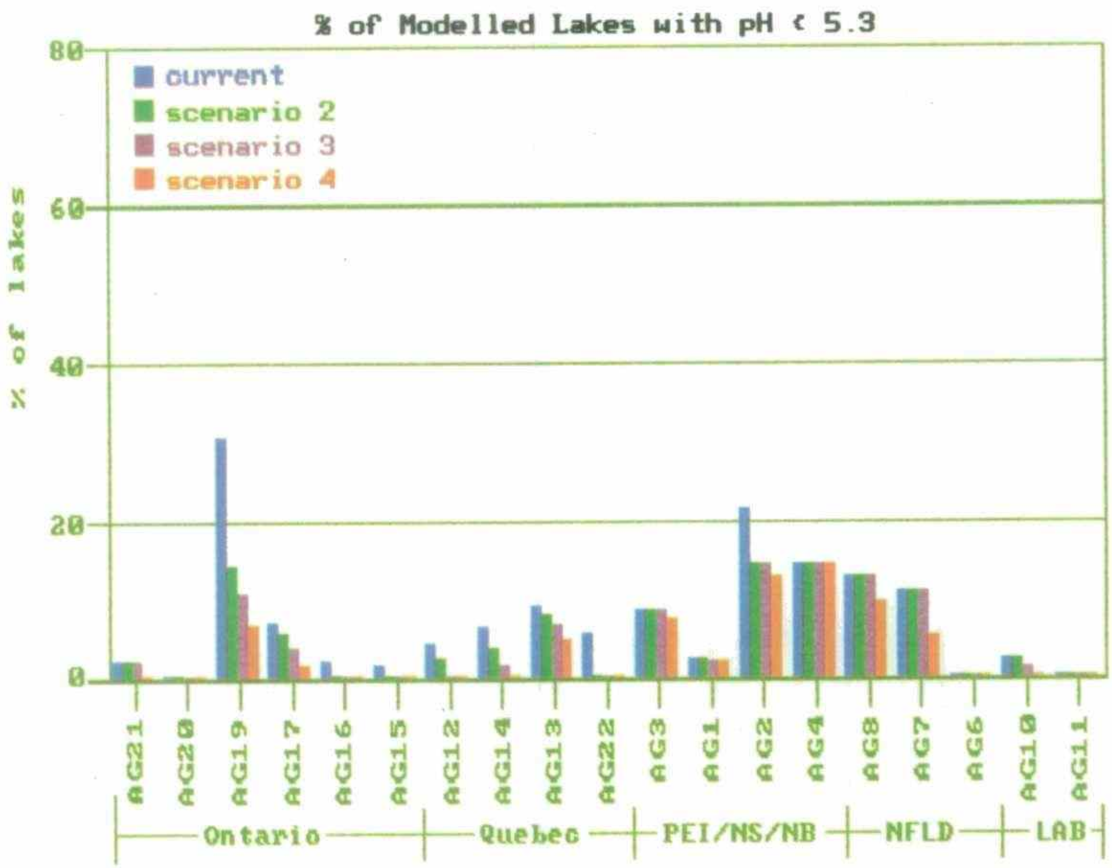


Figure 1.5.5 Critical load values. Coloration indicates critical values designed to maintain at least 95 percent of the lakes in a region at a pH of 6.0 or higher. Numbers on map refer to the grouping or aggregation of tertiary watersheds.





Figs. 1.5.6 and 1.5.7: Predicted number of lakes having pH < 6.0 and pH < 5.3 within each aggregate (watershed grouping) for the four sulphate deposition scenarios. The location of each aggregate is shown on Figure 1.5.5.

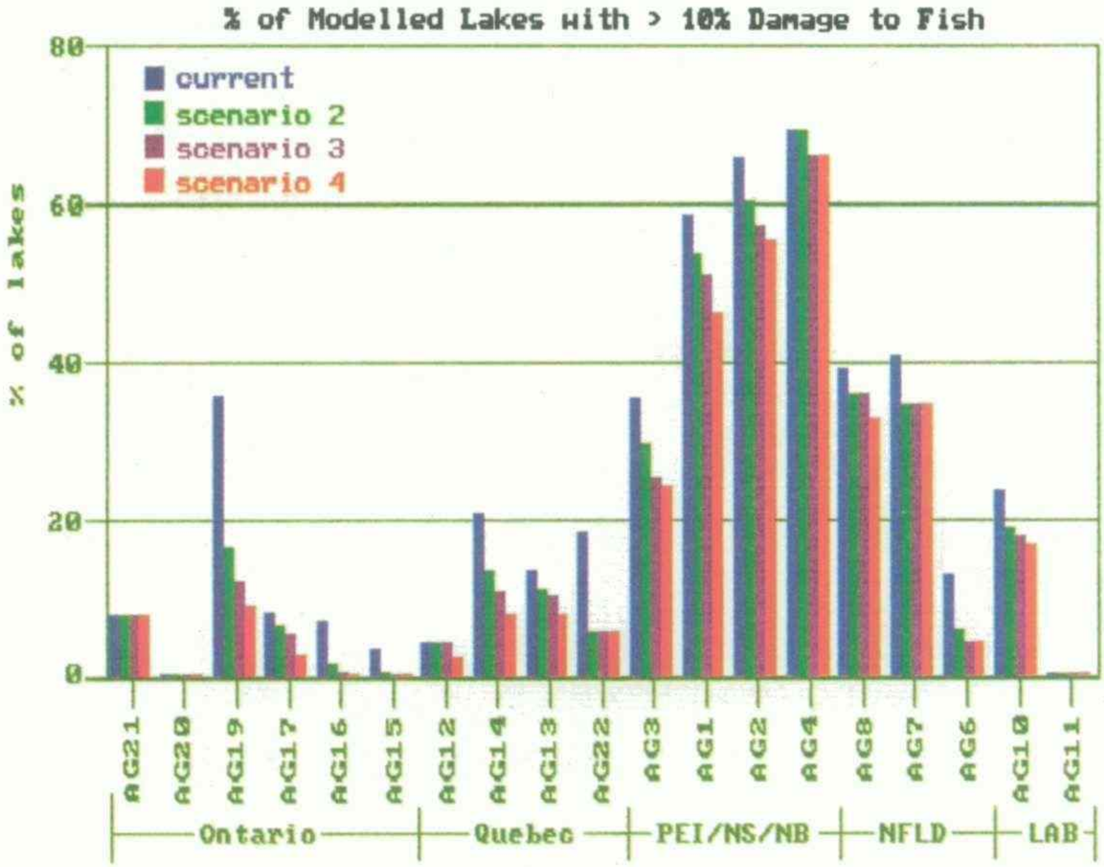


Figure 1.5.8 Predicted percent of lakes in each aggregate (watershed grouping) with greater than 10% reduction in fish species richness (fish damage level) for the four sulphate deposition scenarios. The location of each aggregate is shown on Figure 1.5.5.

However, the models predict little improvement in fish species richness in the Atlantic Provinces. For example, 59, 54, 51 and 47 percent of modelled lakes exceed the fish damage level in southern Nova Scotia and southern New Brunswick (Aggregate 1) for the four Scenarios, respectively. For nearby northern Nova Scotia and northern New Brunswick (Aggregate 3), however, the damage level is at 36, 30, 26, and 25 percent because the terrain is less sensitive.

Improvement in water quality will be apparent well within a decade of reducing the deposition although complete recovery could take 50-100 years depending on the terrain characteristics.

1.6 WHAT ARE THE POTENTIAL SHORT-TERM MITIGATIVE MEASURES, THEIR LIKELY CONSEQUENCES AND ANTICIPATED SUCCESS?

The most common approach for mitigating the impact of acidification of inland surface waters on the fishery resources is the application of limestone or other alkaline materials to lakes and rivers to neutralize the acid input. Neutralization or "liming" has been used extensively to successfully treat the symptoms of acidification in Scandinavia. Liming is also in use in the United States, with both operational and experimental programs in place.

In Canada, experimental liming is being employed at a few sites and has proven effective for the preservation of a wild indigenous strain of Atlantic salmon and the restoration of a reproducing lake trout population. However, the increased pH and acid neutralizing capacity that result from liming are temporary effects, and continuous reapplication is required as long as the lakes and streams continue to receive acidic deposition.

Research in Quebec and in Europe has shown that forest fertilization can correct nutrient imbalances and restore vigour to declining trees. In Quebec an operational fertilization program for sugar maple stands has been implemented. In 1989 approximately 6,200 ha in the Beauce Region were treated.

1.7 WHAT ARE THE FUTURE DIRECTIONS FOR LRTAP RESEARCH AND CONTROL ACTIVITIES?

1.7.1 RESEARCH & MONITORING

With the implementation of control programs for SO_2, NO_x and VOCs in Canada and the United States, long term monitoring of emissions, atmospheric deposition, air concentrations, and aquatic and terrestrial systems need to be carried out to:

- assess the effectiveness of the control programs, the ecological responses and the rate of response;

- validate critical loading values and the physical and biological models in order to improve the predictions for the long term ecological response.

- obtain a better understanding of the natural variability within the physical and biological systems;

- learn more about the atmospheric processes that control the formation of acid deposition.

Where possible and appropriate, integrated ecosystem monitoring, which involves the monitoring of all aspects of the climatic, hydrological, geochemical and biological conditions of a catchment, should be undertaken. Integrated monitoring not only identifies changes in ecosystems, but provides sufficient data to generally say why the changes are occurring.

Additional research will be needed to determine the areas, particularly in Atlantic Canada, that will not be fully protected after the Canadian and U.S. control programs are implemented. Information from the monitoring programs must be used to validate critical loads values. Further analyses of the effect of the U.S. control program on wet deposition should be undertaken when more details become available. The extent of the aquatic resource at risk needs to be better defined. Studies on the feasibility and acceptability of mitigative measures for aquatic systems might also be carried out.

With the implementation of SO_2 control programs, some areas of the LRTAP research program must address the causes and effects of ground level ozone. There is a need to better understand and quantify anthropogenic and natural sources of NO_x and VOCs. Atmospheric research must focus on understanding the relationships between NO_x and VOC emissions and the resulting ambient levels of these compounds and their products, i.e. ozone and peroxyacetyl nitrate (PAN). Atmospheric models need to be developed and/or modified, evaluated and applied to assess the effectiveness of proposed ozone control strategies.

Within the aquatic sciences there is a need to improve the ability to differentiate amongst the aquatic impacts of sulphur deposition, nitrogen deposition, organic acids and other contaminants such as metals or toxic organics, and also to understand their interrelationships. Special attention must be paid to understanding the effects of nitrogen deposition and to determining critical deposition loadings for nitrogen. Small lakes (less than one hectare in size) make up a large proportion of the Canadian lake resource in terms of numbers and are important habitat for some aquatic species. Since almost no information exists on their chemical and biological status, surveys of small lakes need to be conducted to close this knowledge gap. There is also a need to better understand the acidification of wetlands and their role in the storage and release of sulphur and nitrogen.

Although air pollutants have been implicated in the maple and white birch declines, the precise role that air pollutants have played in these declines remains to be defined. The contributory roles of disease, insect attacks, climatic extremes, soil nutrient status, ground-level ozone and acid deposition in forest decline must be determined. Recent forest fertilizer trials have indicated that remedial, mitigative measures may alleviate decline symptoms. These trials should be extended over a number of years and include a range of site conditions. In order to assess whether the current control programs will be sufficient to protect the terrestrial environment, there is a need to determine what sulphate and nitrate deposition loadings, and what ozone concentrations, can be tolerated without

significantly affecting the terrestrial environment. There is also a need to re-evaluate ozone exposure parameters for economically important crops to account for the cumulative and episodic nature of ozone concentrations throughout the growing season.

Human health effects research must continue to address the linkage between human respiratory problems and exposure to acid aerosols, both alone and in the presence of ground-level ozone. The potential for cumulative effects of exposure to acid aerosols and/or ozone must also be investigated. Aerosol acidity measurements are required for the areas of the country which receive high levels of LRTAP. Southern Ontario and southern Quebec, where the population densities and potential for LRTAP are greatest, need particular attention. There is a need to develop critical measures for ozone and acid aerosol exposure which would reflect health hazards for both short and longer term exposure.

An estimated 300,000 people from acid sensitive areas of eastern Canada obtain their drinking water from unregulated sources (often ground water) that may be affected by acid deposition. Additional monitoring of such water supplies for the presence of toxic heavy metals is required before the risk to public health can be evaluated. More studies on metal speciation, bioavailability, and bioacculumation are needed to determine if acid deposition is causing increased contamination of fish and other foods.

1.7.2 CONTROLS

Emissions projections for the next 15 years show that SO_2, NO_x and VOCs emission rates will begin a slow climb beginning early in the next century. This is largely due to the expected increase in the number of sources linked to projected overall economic growth. Future emission controls will need to deal with projected emission increases beyond the current control horizon. Any future controls will also have to respond to modified environmental protection needs as they arise from new research results.

In addition to acid deposition and ozone, toxic air pollutants and global warming are demanding greater attention. The necessity of dealing with several interrelated problems simultaneously will require that the approaches to each issue be strategically linked to ensure proper coordination. The evaluation of such complex interlinked programs may require that socio-economic models be developed and used to determine the best management decisions.

Current abatement technologies are targeted at solving specific problems and are usually remedial measures which carry an energy penalty or produce other pollutant streams. Advanced emission reduction options, which solve more than one environmental problem simultaneously and which enhance energy efficiency, need to be developed, demonstrated and deployed in the future. A broader preventative approach for dealing with environmental issues will also need to be found, including product substitution, new process technologies and alternative ways of meeting societies' needs.

APPENDIX I: AUTHORSHIP OF ASSESSMENT REPORTS

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